THE UNIVERSITY OF ALBERTA

THE FROST HAZARD FOR AGRICULTURE IN NORTHEAST ALBERTA

by

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF ARTS

DEPARTMENT OF GEOGRAPHY

EDMONTON, ALBERTA

FALL, 1970

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled THE FROST HAZARD FOR AGRICULTURE IN NORTHEAST ALBERTA submitted by Roger Hayter in partial fulfilment of the requirements for the degree of Master of Arts.

ABSTRACT

The theme of this thesis is the frost hazard for agriculture along the northeastern margin of cultivation within Alberta.

Frost is both a constant limitation to the range of agricultural practices and a sporadic killing hazard. The purpose and methodology of this thesis is to holistically appraise the frost hazard. With respect to the short frost-free season, the adequacy of moisture and heat and the effect of photoperiodism on plant growth is assessed. To complete the holistic appraisal agricultural adjustment and farmers' perception of the frost hazard are discussed.

The physical components of the frost hazard are analysed on the basis of the meteorological records, 1959-68 and on the basis of temperature traverses conducted in the fall of 1969. Questionnaire returns provided the basic data for the analysis of farmers' perception of the frost hazard.

The untimely occurrence of frost results directly in substantial yield losses in occasional years and reduces quality of the crop in many years. Whilst heat availability for plant growth is generally sufficient during the growing season there is a significant number of years when this is not the case. For the study area photoperiodism should not be considered a factor of any importance in terms of rate of growth. Total moisture sufficiency is not usually a problem but excessive rainfall in August and September frequently delays harvesting until late September and October, and even until the

following spring.

The intensity of the frost hazard varies according to the sum of topographic effects. Within the study area there is no general regional, variation in frost occurrence; instead micro-climatic variations are significant. Micro-climatic factors seriously 'distort' the representativeness of the minimum temperature records of meteorological stations within the area. This is particularly so for those stations that have recorded long frost-free seasons.

Agricultural practices are not adjusted to the short growing season. The extensive production of wheat is the most important single maladjustment to the frost hazard. There is also a need to improve considerably the selection of crop varieties, use of fertilisers, use of better quality seed, and land use allocation.

Lack of adjustment results partly from the manner in which farmers perceive frost. Frost is accepted as an integral part of farming in this area and is regarded as 'an act of God' against which nothing can be done. The ramifications of the frost hazard are not generally understood. However, the better perceivers of frost damage are also economically, the most successful.

To summarise, the shortness of the frost-free season is the most significant physical restriction to agriculture. There is a need to equate economic success with ecological adaptation. Both the frost hazard and market forces suggest a feed- and livestock- based farming economy.

ACKNOWLEDGEMENTS

I very sincerely thank Dr. Proudfoot who has been a continual source of help, ideas and encouragement in the writing of this thesis. I am deeply indebted to him.

I also gratefully acknowledge Professor Longley's advice and comments in both the research and writing side of this thesis.

I am also indebted to my external examiner Dr. Kondra for his very willing help on certain specialised aspects with which I had only a scanty knowledge.

I warmly thank Jack Chesterman, for the quality of the maps contained within this thesis are almost entirely due to his skill and care with the camera.

I should like to thank too Dianne Rose for processing my data on the computer.

I am grateful to Cecile Dion for typing both the draft and final copies of this very long thesis.

Finally, I should like to thank all those farmers who gave of their time to answer my questionnaire.

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INTRODUCTION

This thesis is based upon fieldwork undertaken during the summer and early fall of 1969 in northeast Alberta. The study itself results from an interest in marginal areas and as such is a continuation of Hozack's work in this region (Hozack, 1969). Hozack illustrated the marginality of northeast Alberta utilising a variety of criteria both physical and economic, although the emphasis was on the economic structure of farms. Amongst the physical factors retarding agricultural progress Hozack found temperature, and specifically the risk of frost damage, to be the most significant. In this thesis an attempt is made to discover the extent to which the frost limitation poses a threat to viable agriculture, and to reveal the way in which individual farmers perceive the frost hazard along this part of the northern fringe of cultivation.

The agricultural marginality of this region is the result of the complex interactions of a wide variety of natural and human factors. Apart from temperature, other problems of the physical environment include maldistribution of moisture, poor soils, hail and stony land. Economically the area's potential is reduced by too many farms, small farm sizes, poor decision-making, a lack of alternative employment, and for the most part, low opportunity costs which seriously reduce mobility from farms. Marginality is also a function of time. Northeast Alberta was one of the last agricultural areas in Alberta to be settled and thus, from the beginning, had to compete with regions which had not only a more advantageous physical base, but also an accumulated stock of

social and farm capital. In this study no attempt is made at an overall assessment of the marginality of northeast Alberta by systematic analysis of all the relevant variables. Rather, the marginal nature of northeast Alberta is viewed through the particular spectrum of the frost limitation. Frost, therefore, provides the focusing concept of the thesis. It is hoped that such an in-depth study of one of the more significant restrictions to northern farming will provide a deeper insight into the problems of agricultural development in northeast Alberta.

The study falls into three main parts. The first section deals mainly with methodological aspects (Chapter I). The second is an attempt to define the frost hazard as completely as possible using physical criteria (Chapters II-IV). The third section involves the role of frost in the decision-making process and an analysis of farmers' perception of the frost hazard.

CHAPTER I

METHODOLOGICAL APPROACH

Previously, frost in relation to crop growth has largely been discussed in terms of its risk of occurrence in spring and fall and by the average length of the frost-free season. On the whole the frost-free season has been isolated as an independent variable discussed in turn with other physical controls of northern agro-climates in North America and Eurasia. Frost poses broadly two different types of problems to the farmer along the northern margin of cultivation. Firstly, frost provides a constant limitation to the range of agricultural practices by virtue of a short, average frost-free season; and secondly, frost is a sporadic killing hazard which can occur at any time during the growing season. An holistic approach to the frost hazard must recognise that the chances of frost damage depends not only upon the meteorological probability of frost occurrence on particular dates in the spring and fall as determined by the temperature records of point locations, that is meteorological stations, but also upon micro-variations in minimum temperature, differences in plant susceptibility to frost during the growing season, the adequacy of heat and moisture supplies for plant growth, the fertility of the soil, and the present range of agricultural practices and possible future adjustments. The agricultural response to the frost hazard is due partly to the manner in which it is perceived by farmers.

It is obvious that frost and the spatial variation of frost

occurrence in association with crop cold hardiness are principal components of the frost limitation. It is also true that any factor which affects the duration of crop growth is a determinant of the frost hazard. It is from this viewpoint that climatic parameters such as rainfall and mean temperature, the physical base especially soil, and human decisions as to agricultural practices are discussed. The frost hazard has, therefore, considerable ramifications, and the format of this thesis represents an exercise in definition at increasingly complicated levels for a particular segment of the northern fringe of cultivation. To begin with, the traditional index of frost risk, the frost-free season, introduces the problem. This is followed by, and related to, a description of the broad climatic elements of the area. This provides a regional framework within which the micro-variation of frost distribution can be analysed in detail for the sample areas. An account of plant resistance to frost completes the physical definition of the frost hazard. This gives the necessary information required to evaluate both current farming practices, possible alternatives, and farmers' perception of the frost hazard.

In fact, natural phenomena can be regarded as hazardous only if losses occur or, in other words, if existing human adjustments are insufficient to prevent damage. There is no absolute physical level of severity for a natural event to become a hazard. For example, there is not a frost hazard to farming in the Arctic because agriculture does not exist there. On the other hand there is a frost hazard to the growers of winter crops in southern Alberta, the fruit growers of British Columbia, and the northern grain farmer. There are, however, considerable differences in the degree of the

frost hazard among the last three areas mentioned. For the first two frost is a sporadic killing hazard whilst on the northern fringes grain farming is conducted every year under marginal temperature conditions, although July and early August frosts can be regarded as sporadic. Russell associates a natural hazard with sporadicity of occurrence, extremeness of magnitude and social disruption (Russell, 1969, pp. 2-7). This is regarded as a rather extreme definition of hazard and this study will regard frost as a hazard because frost is a cause of crop losses and agricultural opportunity is restricted by the short frost-free season.

Natural Hazard Perception

Although there are considerable differences from much previous work, this thesis falls within the field of natural hazard perception, the broad aims, procedures and findings of which have been outlined by Burton *et al*. (Burton, Kates, and White, 1968). Work in this field has emphasized extreme geophysical events, for example sea damage, river floods, tornadoes, earthquakes and drought, which, while sporadic in frequency, do result in a large degree of human suffering and social dislocation. The physical magnitude and the socio-economic costs of these events are considerable and although usually affecting a relatively small percentage of society, information about such events is thoroughly disseminated, in advanced countries at least, by the news media. This thesis departs from previous work in that there are frequently no marked visual effects resulting from frost damage, and frost as considered here does not cause direct human suffering. Moreover, the spatial extent of frost damage cannot readily

be demarcated, and frost damage itself is often not easily isolated from other causes. Furthermore frost constitutes both a sporadic hazard causing extreme crop losses and a permanent limitation to agricultural development. Frost damage is not extensively reported through public information channels, and even within agriculture, research on the nature of frost damage has concentrated upon horticultural crops. The northern grain farmer has had to rely to a large extent upon personal experience and observation to provide himself with knowledge on frost damage and the best hazard reducing practices to adopt.

This thesis also differs from many natural hazard perception studies in its purpose of investigation. Hazard perception studies generally contain three major foci of interest, beginning with an evaluation of the hazard itself, then a description of the existing level of adjustment and range of possible alternatives, and finally an account of how men perceive both the hazard and hazard reducing practices. In many cases the physical aspects of the hazard have been assumed as given, usually expressed merely in terms of hazard zone occupance. This is feasible where the hazard is infrequent through time and easily defined spatially. Even where the hazard has been thoroughly defined by physical parameters, emphasis has been on the perceptive processes and behavioral responses to the hazard in question. The real purpose has been to elucidate patterns, spatial or otherwise, in perceptiveness and to isolate the main factors in the decision-making process in face of crisis, in order to suggest behavioral adjustments to the hazard in addition to the existing, and potential, technological adjustments.

The approach opted for here is more concerned with an holistic appraisal of the frost hazard itself, utilising several lines of inquiry including an analysis of current farming practices and the manner in which farmers' perceive the frost hazard and risk-reducing practices. Farmers' perception is studied primarily to obtain a better understanding of chosen practices and adjustments to the frost hazard. In its methodological approach, this thesis owes much to Rooney's work on the urban snow hazard in the United States. His study was,

". . . designed to assess the impact of snow in urban areas, using several lines of investigation. Snow's disruptive effects on man are analysed with an emphasis on the identification of the critical physical - environmental variables (amount and kind of snow, wind, temperature, terrain and so on). Then the role of community adjustment and adaptation is examined, and, finally, attitudes concerning the snow hazard are probed, by means of interviews, to gain an understanding of the adaptations and adjustments that are characteristically made." (Rooney, 1967, p. 538).

While a similar methodology is adopted in this study, an attempt will be made in Chapter VI to compare and contrast the analysis of farmers' perception of the frost hazard with those perception studies of more extreme geophysical events. Following Rooney, however, the critical physical factors will be examined first.

The Climatic Background

The basic agro-climatological elements of the northern areas of Alberta are well known, and include the restricted nature of the

growing season within which vagrant summer frosts can occur, relatively cool temperatures, low evaporation rates, low rainfall with a summer maximum, low specific air humidity and long summer day lengths. The limited growing season and the susceptibility to summer frosts is broadly a function of a northerly continental situation. The absence of a mountain barrier to the north allows the influx of cold arctic air, while other features of such locations include long distance from warm areas thus reducing heating by advection. Two basic types of frost, radiation and advection frosts, result from a combination of some or all these factors. Advection frosts occur when cold air masses move into the region from the north. From a topographical point of view such frosts are frequently widespread and can be associated with strong winds. This was the case, for example, on June 10, 11 and 12 of 1969 when cold air from a high pressure system located to the west of Hudson Bay, reduced temperatures by as much as 12°F below freezing, even causing frost in the southern part of the Province. Radiation frosts occur normally under stable high pressure conditions, when nocturnal radiation reduces the temperature below freezing. These frosts are associated with clear skies, calm winds and frequently an inversion of temperature. Lower areas are most prone to radiation frosts. Frosts can also occur as a combination of these two types, when, for example, cold air blows in during the day and the wind drops at night. In this case radiation effects emphasize the existing low temperatures.

Temperature restrictions are present not only in the form of short frost-free seasons but also in the lowness of maximum temperatures. Across northern Alberta, mean temperatures for July,

the hottest month, are only 62^{o}F, whilst the number of summer days with a maximum above 80^{o}F is about 15 (Longley, 1968, pp. 2-3). temperature limitations are partially compensated for by longer day length (plant growth responds to the duration of the daily light period, a factor known as photoperiodism), large amounts of insolation, and by decreasing altitude towards the north. The average number of hours of bright sunshine between May 1 and September 30 is 1200 and this gives a good indication of the duration of sunlight available for plant growth (Longley, 1968, p. 4). Within Alberta, only the southeast enjoys greater insolation. Precipitation supplies are slight, this resulting largely from a continental situation in the lee of the Rocky Mountains. However, while rainfall is light, it tends to be well distributed throughout the summer, and is associated with relatively low evaporation rates. For northern Alberta, mean precipitation, 1931-60 between April 1 and September 30 is 12-14" of which 3" fall in each of June and July and 2.5" in August. In the extreme north of the Province, well beyond the limits of continuous cultivation, mean rainfall in this period drops to 10" and below (Longley, 1968, pp. 5-6). Convectional precipitation in the form of hail also constitutes a hazard to farming, but the effect of this phenomenon decreases from central Alberta to the northeast (Paul, 1967, p. 5). At Lac La Biche the number of hail days per year is only 2.0 and in the Peace River District the number is less than this (Paul, 1967, p. 5).

The extent to which these various climatic factors, such as frost-free season, day length and low rainfall, are emphasized as restrictions on agricultural progress varies considerably.

Agro-Climatic Interpretations

Many writers have found temperature, especially in terms of the short frost-free season, the most significant constraint to agricultural development in the north. "Northward, temperature rapidly becomes the predominating factor, and any shortening of the frost-free season from lack of precipitation is of secondary importance" (Currie, 1959, p. 6). Unstead had made the same point forty years previously (Unstead, 1912, p. 421). Various authors have used temperature isolines to delimit both the potential and practical limits to wheat cultivation. Unstead based his potential limit on the accumulated number of degrees above 41°F during the growing season, modified by elevation and day length. He found that the greater part of Alberta was capable of producing wheat and that there was sufficient heat to permit wheat cultivation in low lying valleys such as the Mackenzie even beyond 60°N (Unstead, 1912, p. 363). Because of its variability Unstead eliminated frost from his empirical formulas. Baker, suggesting 57°F as the critical mean summer temperature (and 63°F for July), drew a very similar northern limit for the possible extension of wheat cultivation (Baker, 1925, p. 402). Koeppe, only slightly less optimistically, suggested a 58°F mean summer temperature (Koeppe, 1931, p. 115).

More recently, and using a theoretical approach, Williams argued that wheat should mature as far north as Wrigley (63° 12') along the Mackenzie (Williams, 1969, p. 269). This is exactly the same northern terminus as that suggested by Unstead in 1912. In drawing his boundaries Williams used latitude, longitude, elevation,

temperature normals and day length and he related them within a biometeorological time scale equation. From this formula Williams considered that not until 57°N was reached was wheat production limited to lower elevations such as broad valley floors and lake shores. However none of these authors considers variables such as the frost-free season, micro-criteria, especially soil and local relief variations and the economic viability of wheat production in such northerly locations. Although noting the modifications of economics (especially transportation costs) and the adverse physical environment Mackintosh found enough field evidence to confirm the limits set by Unstead and Baker (Mackintosh, 1934, p. 191).

Taking a more empirical approach, other authors have found the length of the frost-free season to have more pragmatic value. At the beginning of the 20th century Reed stated,

"There is very little agriculture, except that based upon wild hay and grazing, where the average season between killing frosts [32°F] is less than 90 days" (Reed, 1916, p. 509).

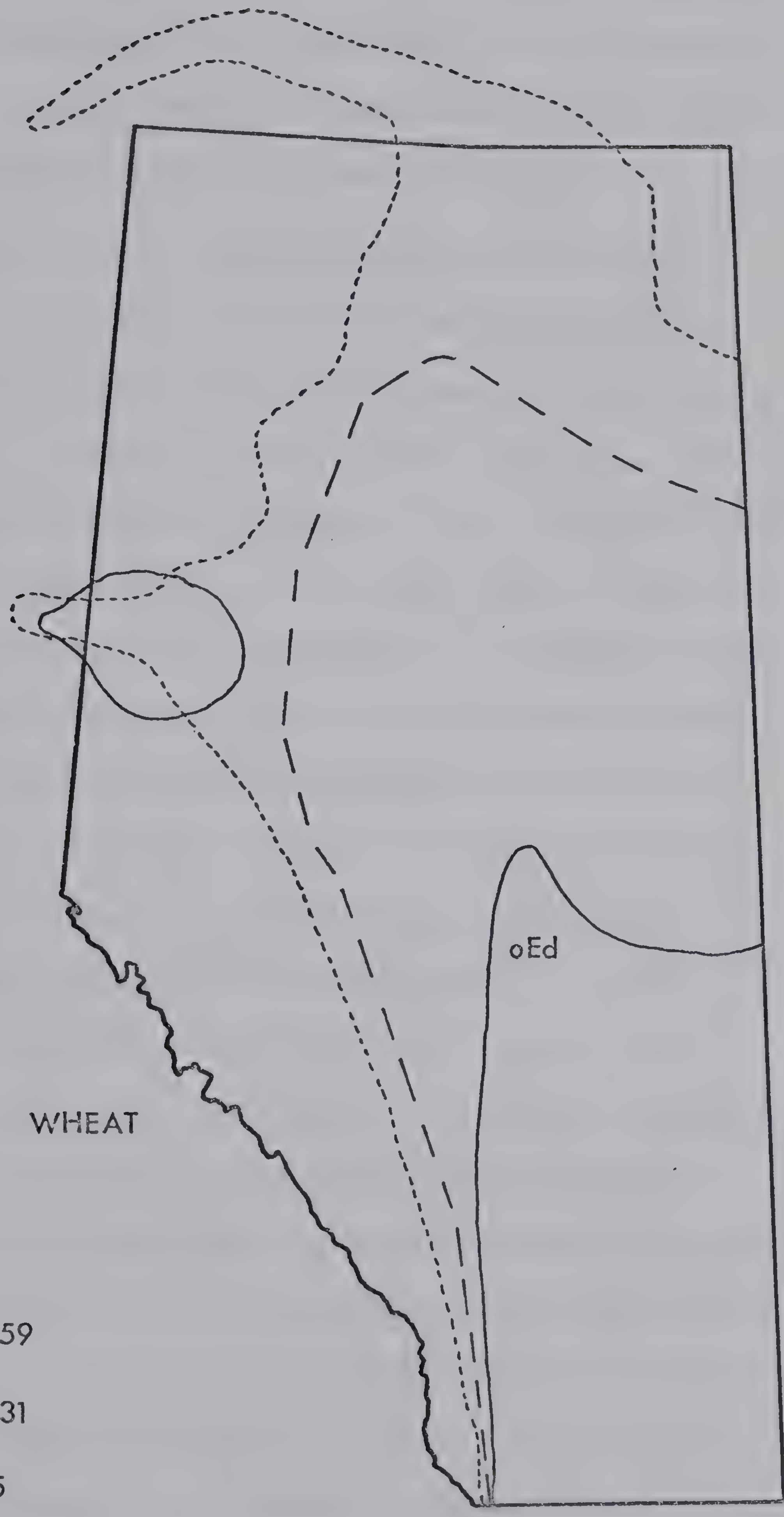
Bennett found the 90-day frost-free isoline, using 32°F as a base, to provide a relatively accurate northern limit to agriculture because of its good visual correlation with the actual distribution of cultivated acreage. For him this substantiated Reed's hypothesis (Bennett, 1959). The above remarks agree well with Leonard and Martin's observations,

"Length of frost-free period is a good index of the practicability of small grain production. Extensive small grain production requires a frost-free period of 100 days or more; a period less than

90 days is precarious, demanding not only prompt seeding but the use of the earliest maturing varieties" (Leonard and Martin, 1963, p. 8).

Some of the above mentioned limits to wheat cultivation have been illustrated (Fig. 1.1). In short, potential limits (e.g., Baker, Koeppe) have been based upon mean daily temperatures, whilst actual limits (e.g., Bennett) have been based upon the frost-free season. However, the temperatures used to define the frost-free period have varied among observers. All the authors so far mentioned use 32°F as the base temperature. Carder, on the other hand favours 28°F as a more critical threshold, and even using this 'killing frost' temperature he suggests a threshold of only 80 frost-free days is required as a minimum for the growth of cereals (Carder, 1965a, p. 22). Indeed Carder considers neither insufficient heat nor the risk of frost to be the greatest limitation to agricultural development in northern Alberta. "Agriculturally, the greatest limitation is inadequate moisture in some years" (Carder, 1965a, p. 7). However, he finds in most years low evaporation and transpiration rates and a well distributed rainfall throughout the growing season offset any moisture deficiencies. "Much of the precipitation comes at the times best suited to crop production" (Carder, 1965b, p. 13). Other agro-meteorologists at the research station of Beaverlodge, Peace River District, have also concluded that variation in precipitation is the single most important factor causing yield variations in northwestern Canada and Alaska (Guitard, *et al*., 1965, p. 5). Whilst noting that low temperatures were often a problem, the authors found only one site in Alaska to suffer frequent frost damage and that "early maturing varieties of all crops usually matured normally at all

Figure 1.1



SUGGESTED LIMITS OF WHEAT CULTIVATION

sites" (Guitard _et al_., 1965, p. 7). Their general conclusion was that early maturing varieties of all cereal crops can be profitably grown, where there is a local demand, in many localities in northern Alberta, the Northwest Territories, the Yukon and Alaska.

Other studies, however, have emphasized the economically marginal nature of northern agriculture and cited the significance of physical restrictions, and particularly temperature, in retarding agricultural progress. Chapman and Brown's work for A.R.D.A. found that the entire area to the north of Edmonton faced 'a serious frost hazard' (Chapman and Brown, 1966, p. 14). Hozack from a field-work-based thesis focusing on the marginal dimensions of farming in north-east Alberta discovered the risk of frost during the growing season to be the greatest limitation to agriculture (Hozack, 1969, p. 21). Chapman and Brown, and Hozack also considered the heat available for plant growth to be sub-optimal. For Hozack the principal question in any year was whether temperatures were high enough to permit ripening before the onset of the first fall frost (Hozack, 1969, p. 33). Chapman and Brown using the concept of accumulated temperature as an index for heat available for plant growth, found that the northeastern fringe of cultivation in Alberta received less heat than any other agricultural area in Canada (Chapman and Brown, 1966, p. 9). As regards moisture, northern agricultural areas in Alberta are ". . . of fairly adequate moisture . . . but it should not be assumed that droughts never occur" (Chapman and Brown, 1966, p. 14).

There are, then, considerable differences in the interpretation of essentially the same statistics with regard to the climatic capability of northern areas in Alberta for agriculture.

This is broadly illustrated by the difference between Baker's 57°F summer isotherm and Bennett's 90-day frost-free isoline (Fig. 1.1). Those who stress the potential of northern lands for cereal cultivation all emphasize the importance of long day length (photoperiodism) for plant growth as the major compensating factor for both the relatively low temperatures and short growing season. Mackintosh remarked that the long summer days also reduced the risk of frost because nocturnal radiation was so short (Mackintosh, 1934, pp. 194-5). He cited evidence for this in the lower frequency of July and August frosts at Fort Vermilion (58° 41') than at Beaverlodge (55° 15'). On the other hand researchers interested in the marginality of cultivation along the northern fringes, from an income point of view, have not been convinced that long day length compensates for the short frost-free season and low temperatures. Indeed Chapman and Brown found the evidence as to the effects of photoperiodism so small that the authors felt obliged to ignore this factor completely in a study of climates for agriculture within Canada (Chapman and Brown, 1966, p. 6).

Agro-meteorological interpretations of northern fringe areas are not therefore consistent. Those who favour the potentiality of the north for agriculture either ignore the variable factor of frost (e.g., Unstead 1912, Williams 1969) or use 28°F as the most appropriate limits of the frost-free season (e.g., Carder 1965a, Guitard, _et al._, 1965). All such authors point to the fact that wheat is grown even inside the Arctic, but none of them indicates the relative poverty of northern agriculture and the role in this played by physical restrictions. Their approach is generally to reveal the

potential, irrespective of socio-economic implications, of northern lands for cultivation. Those workers looking for physical reasons for the comparative disadvantage of northern agriculture have found the frost-free season, based upon 32°F, to be the best single indicator of regional marginality that has been empirically justified (e.g., Hozack 1969, Chapman and Brown 1966). Areas of dispute in the climatic interpretations of northern agriculture particularly revolve around the effects of frost and photoperiodism, whilst adequacy of moisture and heat cause less argument. These regional, climatic components will be examined in detail for a particular segment of the northern margin of cultivation in the next chapter.

Objectives

The principal objectives of this study can be outlined as follows:-

1. To assess the frost hazard more completely than has been attempted before by relating the meteorological probability of frost to a variety of physical and human criteria which have important consequences as to the probability of frost damage.
2. To evaluate certain pertinent 'bones of contention' in the agro-meteorological interpretations of northern fringe areas especially as regards minimum threshold values of the frost-free period and the amount of heat required for plant growth.
3. To evaluate the viability of the present structure of farming in terms of the frost hazard and to suggest practices

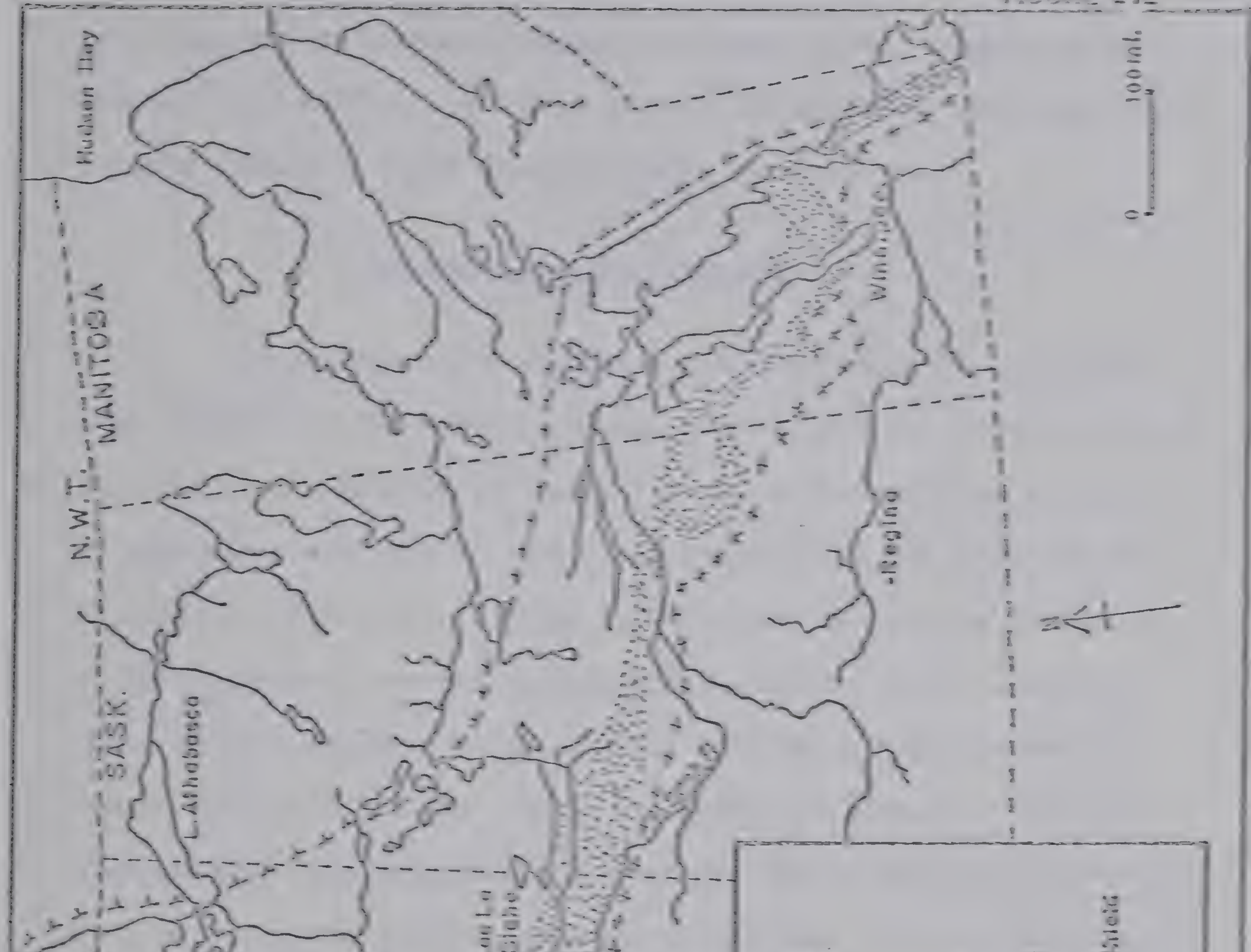
that will reduce the risk of the hazard.

4. To describe and analyse individual farmer's perception of the frost hazard primarily to understand better the adjustments made in response to the frost hazard and to make appropriate suggestions for improvement. Attempts will be made to show the relationship, spatial and otherwise, of farmers' perception to the intensity of the frost hazard and degree of experience with the frost hazard, and the significance of various socio-economic variables in the perception process.

The Study Area: Criteria for Selection

The underlying requirement for the study area was that frost had to be a significant restriction to agriculture. This meant a location along the northern fringe of cultivation. Given the limits of continuous cultivation (Fig. 1.2) two areas within Alberta seem to be suitable, the northwest (Peace River District) or the northeast. The area between the two has in fact very little agriculture, being one of relatively high and broken relief and very poor soils. Northeast Alberta was chosen because of Hozack's work there in the previous year, proximity to Edmonton and because of an agricultural climate considered to be no more favourable than the Peace, despite its more southerly location. Carder in describing the climate of northwest Canada, states, "First, it should be pointed out that . . . the climatic zones are not arranged latitudinally but slope off to the south-east" (Carder, 1965a, p. 21). According to Chapman and Brown northeast Alberta in fact receives a slightly shorter frost-free season

FIGURE 1.2


THE AGRICULTURAL FRINGE
The Agricultural Fringe
Southern Margin of Forest
Southern Margin of Canadian Shield
After: Vanderhill, 1962
B.C.
ALBERTA
SASK.
N.W.T.
MANITOBA
Hudson Bay
L. Athabasca
Lac La Biche
Edmonton
Regina
Winnipeg
0
100 mi.

and lower amounts of heat (Chapman and Brown, 1966). Longley gives the two areas similar frost-free periods but the Peace River District slightly less heat units (Longley, 1968 , pp. 3-4).

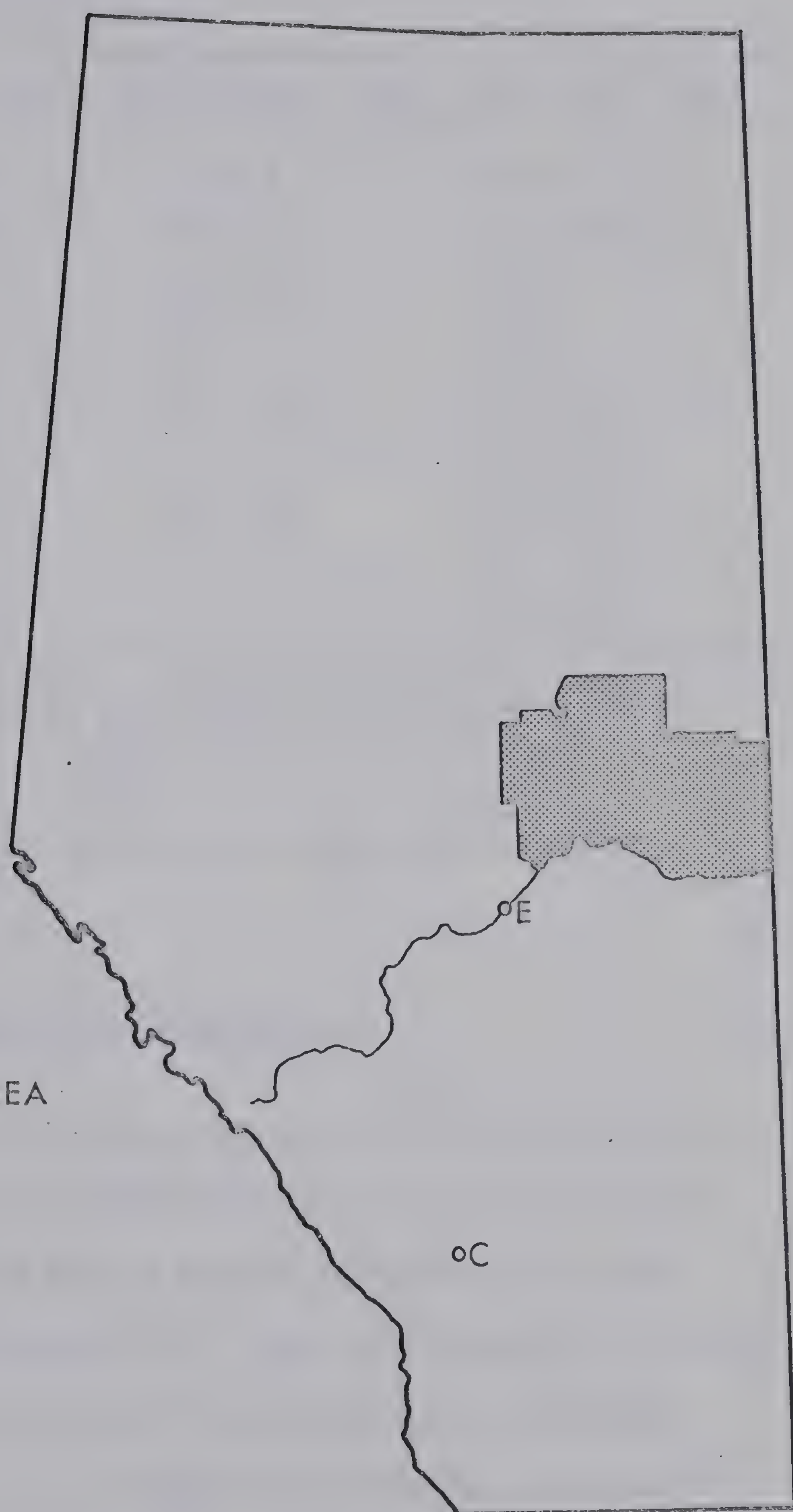
Northeast Alberta: Location

The study area's location is generally described as 'Northeast' Alberta not because of its geographical position in the northeast quadrant of the Province but because it is on the northeast boundary of continuous cultivation. The study area lies to the north and east of Edmonton (Fig. 1.3). Factors in delimiting the precise boundaries of the study area were the distribution of meteorological stations, which provide the basic climatological data for the thesis, and the census division boundaries within which they are situated. The study area contains nine meteorological stations which provide the locational foci of the sample areas. Such a large area was chosen to obtain as great a spatial variation in the frost hazard as possible. Among these stations there was an average variation of nearly 40 days in the frost-free season for the period 1951-64 (Table 1.1). This table also illustrates the average frost-free period, where the records are available, prior to 1951.

The study area encompasses all the continuously cultivated acreage of Census District 12 and the Athabasca and Thorhild Counties of Census District 13, totalling 3,106,329 acres in all. The latitudinal and longitudinal coordinates of the study area, and the location and names of the sample areas within the counties and improvement districts of the census divisions are illustrated in Figure 1.4. The Athabasca, Lac La Biche, Iron River and Cold Lake sample areas

Figure 1.3

LOCATION OF STUDY AREA



all lie at the northern margin of cultivation.

Table 1.1 Frost-Free Period 1951-64

Average Values

	Frost-Free Period		Last Spring Frost	First Fall Frost
Athabasca[2]	84	(59)	June 8	August 31
Meanook	117	(110)	May 21	September 15
Rochester[1]	79		June 12	August 30
Newbrook[1]	81		June 6	August 26
Lac La Biche[2]	117		May 22	September 16
Vilna[1]	85		June 9	September 2
Iron River	103	(68)	May 28	September 8
Cold Lake	116		May 23	September 11
Elk Point	95	(64)	June 2	September 5

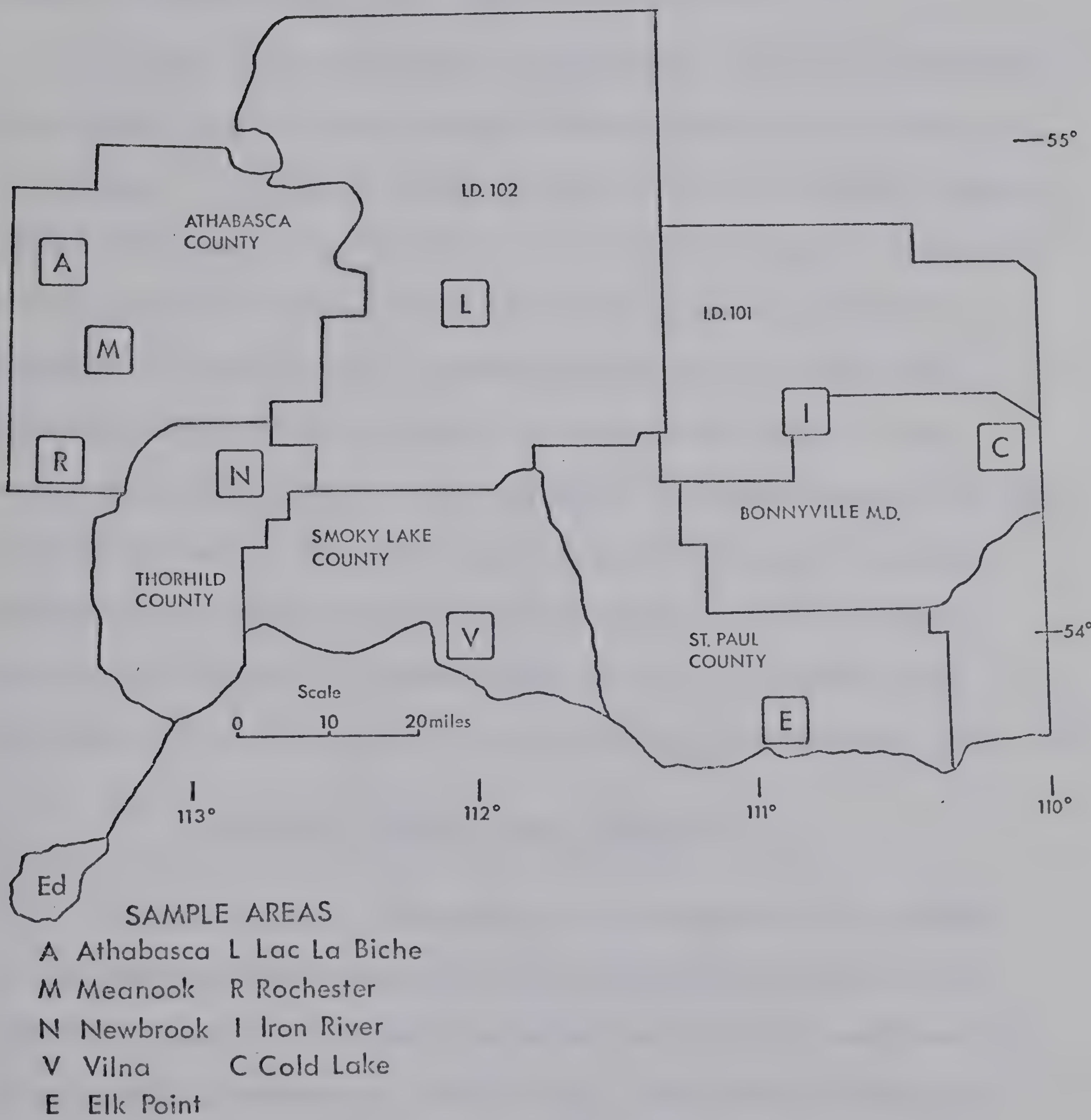
Source: Longley, 1967, pp. 244-245.; [1]Longley, Pers. Comm., Aug., 1969. [2]These are not the same stations as used in the remainder of the text. In both cases the station was dismantled in the early 1960s.

N.B. The bracketed figures are for the frost-free period, where available, prior to 1951.

Northeast Alberta: Physical Background

The area lies on the northern fringe of cultivation of the Western Canadian Prairies and is characterised by undulating terrain, deeply dissected in parts, and with a general decrease in altitude towards the north of approximately 150'. Most of the region is drained in the west by the Athabasca River and its tributaries, especially the Tawatinaw; in the north by the Beaver River system; in the south by the North Saskatchewan River which is the southern boundary of the study area. The area is physically transitional in every sense of the word. On a regional scale the soils change from black to grey

LOCATION OF SAMPLE AREAS Figure 1.4



wooded, the vegetation from 'aspen parkland' to Boreal mixed wood and "The climate is characterized by a transition from the prairie to the northern climatic regions" (Schultz, 1966, p. 26). Virtually all the agro-climatic regions ever drawn for Alberta identify the North Saskatchewan as it flows east from Edmonton as a zone where the climatic base for agriculture changes for the worse.

Soil types are perhaps the best single index for a physically transitional area. Within northeast Alberta variations in soil type are frequent and there are large expanses of dark grey wooded and grey wooded soils, patches of black soils, a wide distribution of peat soils, and a not-so-extensive distribution of poor sandy soils. Stoniness of soils is also a problem in many parts of this area. Generally the area may be regarded as part of the region of grey wooded soils, which is the least fertile of the major agricultural soil groups of Alberta. The soils are particularly deficient in plant nutrients. According to the preliminary soil survey of Northern Alberta more land in the relevant areas of census division 12 has soils not suitable for cultivation than is suitable (Schultz, 1966, p. 33).

Northeast Alberta: Human Background

The study area, especially the northeastern half, was one of the last areas to be agriculturally colonized in the whole of Alberta. Extensive settlement was associated with the development of the railway (Mackintosh, 1934, p. 44). Rail transportation did not reach Bonnyville, 40 miles south of Iron River until the early 1930s. In fact during the depression years of the late 1920s and 1930s the number of farms increased in northeast Alberta whilst the

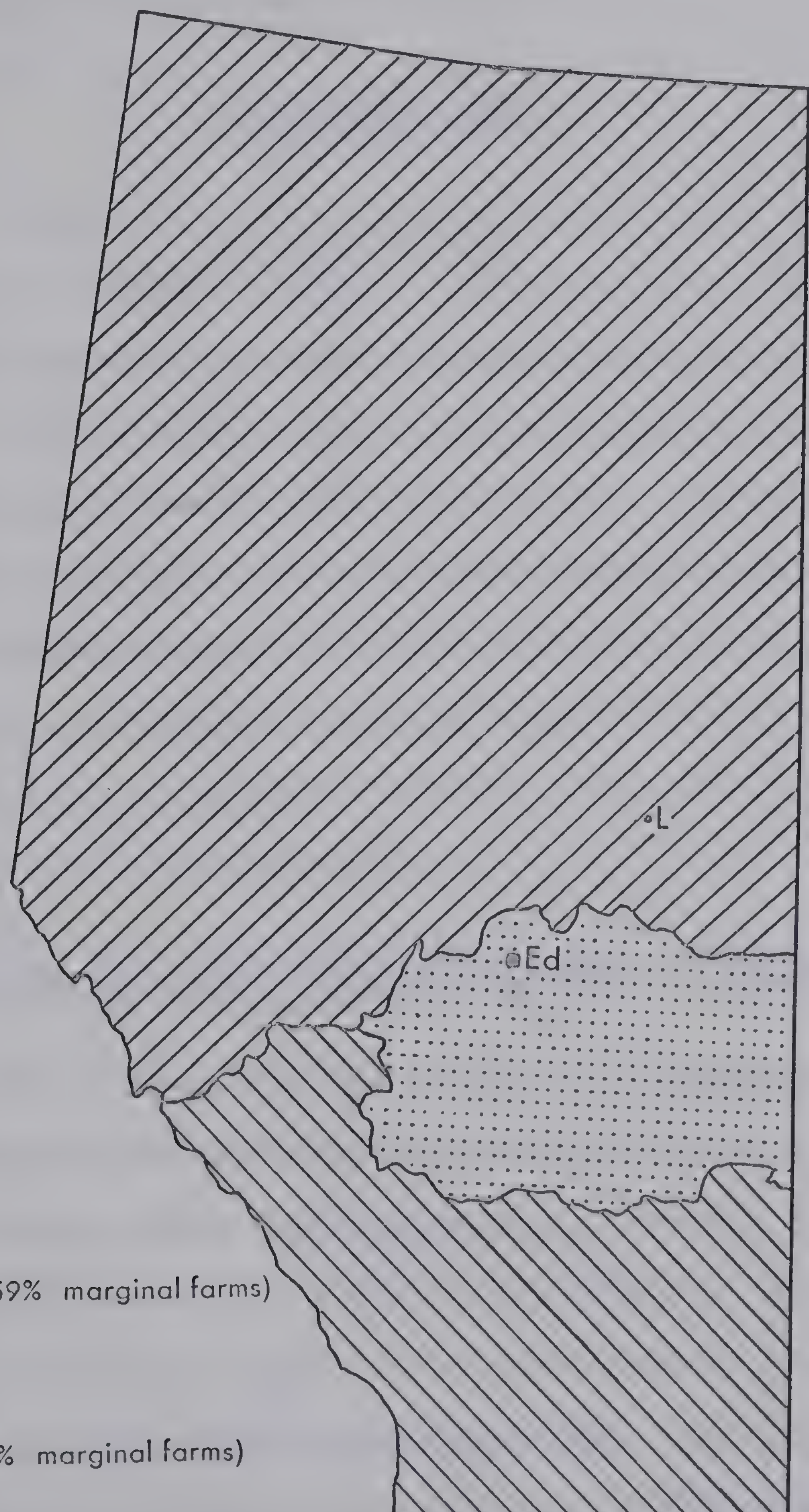
provincial trend was for a slight decline in these years until the start of the 1939-45 war. Between 1931 and 1941 the number of farms in what is now census division 12 increased from 4711 to 5787 (an increase of 22.8%), whilst for Alberta, numbers rose only by 2.3% from 97, 408 to 99,732 (Agricultural Census of Canada, Alberta, 1941, Tables 1 and 28). The end result of colonization was a predominantly agriculturally based economy operated by many diversified ethnic groups. The French, Ukrainian and British in that order are the predominant groups, this frequency being unusual for Alberta in the relatively low dominance of the British and the fact that Germans and Scandinavians are not so well represented (Atlas of Alberta, 1969, p. 56). This wide ethnic base provides an extra sociological variable with which to test hypotheses relating to the preception processes.

The most important socio-economic characteristic of this area is the low level of agricultural income (Fig. 1.5). In 1966 the average gross income per farm in census division 12 was $3,950 and for Alberta, $8,079 (Alberta Dept., of Agriculture, 1968, p. 63). The poverty of agriculture in this area is particularly important because agriculture constitutes the major regional source of income. In 1966 agriculture provided census division 12 with 85% of its income while 46% of the labour force were in agriculture (Alberta, Dept., of Agriculture, 1968, pp. 58-59). These figures can be expected to be even higher for the study area where virtually all the agriculture of census division 12 exists. Occupationally, agriculture is much more important in the study area than in the province as a whole. The economic marginality of the area cannot be related to a single cause, as Schultz notes,

istribution of Marginal Farming in Alberta

Figure 1.5

Incomes less than $3,750



Northern Region (59% marginal farms)

Central Region (38% marginal farms)

Southern Region (21% marginal farms)

urce: Hozack,1969

". . . it is not established beyond reasonable doubt if it is the barreness of nature, or the social history of false beginnings and capital-starved frustrated settlers which accounts for the present state of agriculture" (Schultz, 1966, p. 34).

Approach to Study

In order to fulfill the objectives outlined earlier and in accordance with previous studies in the field of natural hazard perception, research procedures followed two different lines of inquiry. The first problem was to analyse the physical components of the frost hazard in as much detail as possible. The second problem was to relate the frost hazard to agricultural practices and to try to assess the importance of frost in the decision-making process and in contributing to the poverty of the area. This second problem is to some extent a function of farmers' perceptions. A sampling problem also had to be resolved.

The Meteorological Record and Temperature Traverses

The physical bases for defining, meteorologically, the frost hazard are the temperature and rainfall records of the meteorological stations within the nine sample areas. These sources provide information as to the heat and moisture availability during the growing season and the risk of frost for the period 1959-68. Of particular importance are the minimum temperature records, from which the frost-free season, the killing frost-free season and the associated dates of occurrence of frost were obtained. These data were supplemented by results from temperature traverses. Temperature traverses provide a

continuous temperature recording along a selected route and may be used to determine the representativeness of each station's minimum temperature record and to assess the effect of micro-climatic variables upon minimum temperatures within each of the sample areas. The results of the traverses, therefore, allow a spatial dimension to be added to the temporal meteorological record of particular sites.

The Questionnaire

In order to discover adjustments made in response to the frost hazard and the attitudes behind these adjustments, a sample of the farming population was interviewed using a questionnaire (Appendix A). The questionnaire is divided into three main parts. The first seeks general socio-economic information, such as type of farmer, size of farm, age, years experience, ethnic background and degree of innovativeness. Also included in this section are details of site and situation of the farm holdings and farmstead. The second section of the questionnaire attempts to reveal farmers' attitudes to frost in terms of the nature of frost damage, the frequency of frost damage, the spatial variation in frost risk, associated weather conditions and the general importance of frost to farming within the area. The final section determines the sort of decisions taken by farmers to reduce the frost hazard, such as, land use, crop types, preventive measures and palliatives (for example, insurance). The questionnaire included both 'open' and 'closed' questions. The closed questions provide a scale which will be used to grade and compare farmers' perceptiveness. After coding the data was subject to a series of cross-tabulations in an effort to determine any relationships

among the various criteria.

All the interviews were conducted after the abnormally heavy spring frosts of June 10, 11 and 12 and before the first fall frost of 1969. This meant that immediate experience with frost was more or less the same for all respondents. This was regarded as an important point because of the significance of immediate experience and memory in the perceptual process. The interviews were conducted on a person-to-person basis because of the fear that some respondents might not have been able to express themselves adequately in writing, especially as many questions required more than one word answers. A postal questionnaire was not used because of the dangers of ambiguity in the questions and the normally low return rate of this method.

Study Period 1959-68

The decade 1959-68 was the most recent period for which meteorological data were available. Ten years would be regarded by many climatologists as too short to calculate accurate climatic averages for an area, although Longley has used a 15-year period (Longley, 1967) and Guitard _et al_. an eight-year period (Guitard _et al_., 1965) in order to provide representative climatic averages for areas within Alberta. However, the purpose of this thesis is not to reveal climatic trends and the 1959-68 period is used because there are sufficient meteorological data to illustrate the climatic ramifications of a short frost-free season, and because the period constitutes the most recent past with which to evaluate farmers' attitudes. Whether the last decade conforms to climatic trends or not, the farmer still has the task of farming each year as it comes. Each

year he has to adjust to variations in the climatic elements. The use of long term records would introduce the problem of climatic cycles, and there is strong evidence to suggest important changes in the climate of Alberta since the beginning of the 20th century. If this is so, it would be nonsense to include in an assessment of the contemporary frost risk records from the 1920s and 1930s. For these reasons discussion of probable frost risk are based upon the 1959-68 data. Where available, probabilities based on longer term records are given for comparative purposes. Unfortunately only Elk Point and Iron River have long term records covering the entire period 1931-60.

Sampling Design

The size and location of the sample areas were determined by the location of meteorological stations and the nature of frost occurrence. Minimum temperatures vary considerably with local topographic conditions and as a result it is not possible to extrapolate the minimum temperature record of the station for any considerable distance without using temperature traverses. However, since there is a detailed record for a certain number of years at nine sites within the study area (that is the sites of the meteorological stations) the sample areas are situated around, or in close proximity to, the meteorological stations. Given the general location, the size of the sample areas are limited principally by the 'rules' which govern temperature traverses (Longley and Louis-Byne, 1966). The traverses are restricted basically to a one and one half hour period around sunrise and cannot be conducted at a speed faster than 40 m.p.h. or else there is a loss of accuracy. It is possible therefore to cover 40 to

50 miles during a traverse. Under these restrictions the sample areas were limited to a size of 49 square miles as this theoretically allowed a complete circuit of a sample area. The actual boundaries of the sample areas were determined by various barriers to the operation of temperature traverses, such as rivers, lakes and non-cultivated areas such as airports and marshes. In all cases, except Vilna, the local district agriculturalist was consulted for advice on the position of the sample areas in order to obtain as fair a representation of local agriculture as possible. This is the same procedure as that utilised by Saarinen when faced with exactly the same problem with his study of drought on the Great Plains (Saarinen, 1966, p. 44).

Within each of the sample areas, the farming population was sampled. A simple area random sampling design was chosen because of the desire to select a representative fraction of the farming population and a representative cross-section of area, to obtain local variations in the frost hazard. This was done by placing a numbered grid over a map of ownership and selecting numbers from a random numbers table. The size of the sample was 11 in each case so that the total sample size was 99. No attempt was made to define a 'farmer' in terms of any economic criteria. Thus some farmers had less than 20 acres cultivated and were virtually retired, others earned less than 10% from farm income, and one of the sample regarded farming more or less as a hobby. The farming population was broadly defined in this way because such conditions represent a typical facet of agriculture within this marginal area, and in order to have as diversified a range of socio-economic conditions as possible to facilitate the cross-tabulation of socio-economic criteria with perceptiveness. Since the sample

was an area random sample farmers with larger acreages had a better chance of being selected (Gregory, 1963, p. 104). Because of this it is thought that a disproportionately large number of sample farms fall into the census category of 'commercial farms'. The only restriction on the sample was the elimination of Indian Reserves because they constitute a distinct and separate group within the agricultural matrix.

Appraisal of Methodology

Perhaps the biggest problem in completing the fieldwork was the size of the study area and the distance between the sample areas, a problem heightened by lack of personal transport. In anticipation of the study's conclusions, variation in the intensity of the frost hazard is primarily a function of micro-climatic factors rather than any regional differentiation. It might, therefore, have been of greater value to have studied fewer sample areas. This would have increased the time spent in each area, enabling detailed land use and soil studies to have been completed. To obtain regional differences in the intensity of the hazard a province-wide study would have been required.

The nature of the questionnaire also posed a few problems. The first point was its bad design with respect to coding. Much time had to be spent on rectifying this deficiency after the questionnaires were completed. However, it is difficult to see how this could have been improved when the range of variables and their significance were not known beforehand. A second problem resulted from the nature of some of the questions, particularly those requiring long answers. Sometimes farmers would fail to see the full implications of such questions and it was found very difficult to suggest the meaning of a

question without giving clues to the answer. On the other hand it might be argued that showing respondents a set of categories from which to choose may result in answers that would not have been thought of otherwise. However, by leaving many questions 'open' more clues about the importance of frost to the individual farmers were obtained. The personal interviews were found to be of considerable benefit in revealing insights into, not only the importance farmers attach to frost, but also the wider problems in the development of the area.

CHAPTER II

THE FROST HAZARD: A CLIMATOLOGICAL STATEMENT

Agro-meteorological interpretations of the limitations imposed by frost in northern agricultural areas have varied. This has been, in part, the result of differences in purpose of the various studies, already reviewed. However, these differences were also shown to be the result of varying opinions as to the minimum threshold requirement of a number of climatic elements and the failure to perceive the implications of a short frost-free season with regard to other physical requirements for plant growth. Apart from frost, the major physical factors affecting plant growth are moisture, warmth, and day length (photoperiodism). Because of the short frost-free season it is essential that these factors do not retard the growth of crops in any way.

The Frost-Free Season

The immediate problem is to define the frost-free season by some criteria meaningful to cereal cultivation. The temperature at which frost normally occurs is 32°F but a plant temperature of 32°F does not usually result in cereal crops being killed or even damaged. Depending upon the stage of growth and various other factors involved in the nature of frost damage, the temperature at which frost frequently results in some damage, and sometimes even total losses, is 28°F. This temperature will be used to define the 'killing' frost-

free season. Experiments have shown that a plant temperature of 28°F is sufficient to damage a wheat crop in the early fall (Geddes *et al.*, 1928). It is common knowledge that in certain, very crucial stages of growth, admittedly when the risk of frost occurrence is least, only two or three degrees of frost will cause considerable damage. Carder prefers 28°F as the most meaningful figure to use in calculating the frost-free season (Carder, 1965a), but standard procedure has been to use 32°F. Although a recorded screen temperature of 32°F rarely hurts crops and a plant temperature of 28°F frequently does result in some damage, there are good reasons to accept the more commonly used 32°F as critical limits of the frost-free season. The most important reason is that,

"With normal temperature distribution at night, the ground is colder than the temperature indicated by the thermometers in the instrument shelter" (Geiger, 1961, p. 99).

All the temperature recordings from stations within the study area are taken from thermometers placed in instrument shelters (Stephenson Screens), approximately 4' above the ground. Pelton also noted this effect with special reference to wheat:

"The air temperature several feet above a wheat crop is seldom the same as that of the leaves or of the air in the immediate vicinity of the plant . . . . Nocturnal radiation from plant surfaces creates conditions that cause many late and early fall frosts on calm, clear nights" (Pelton, 1967, p. 216).

At Beaverlodge minimum temperatures 5cm above the ground were on average 8°F below those recorded in the instrument shelter

for the period May to October, 1968 (Table 2.1). Beaverlodge was chosen because it is the nearest station to the study area recording grass minimum temperatures north of Edmonton.

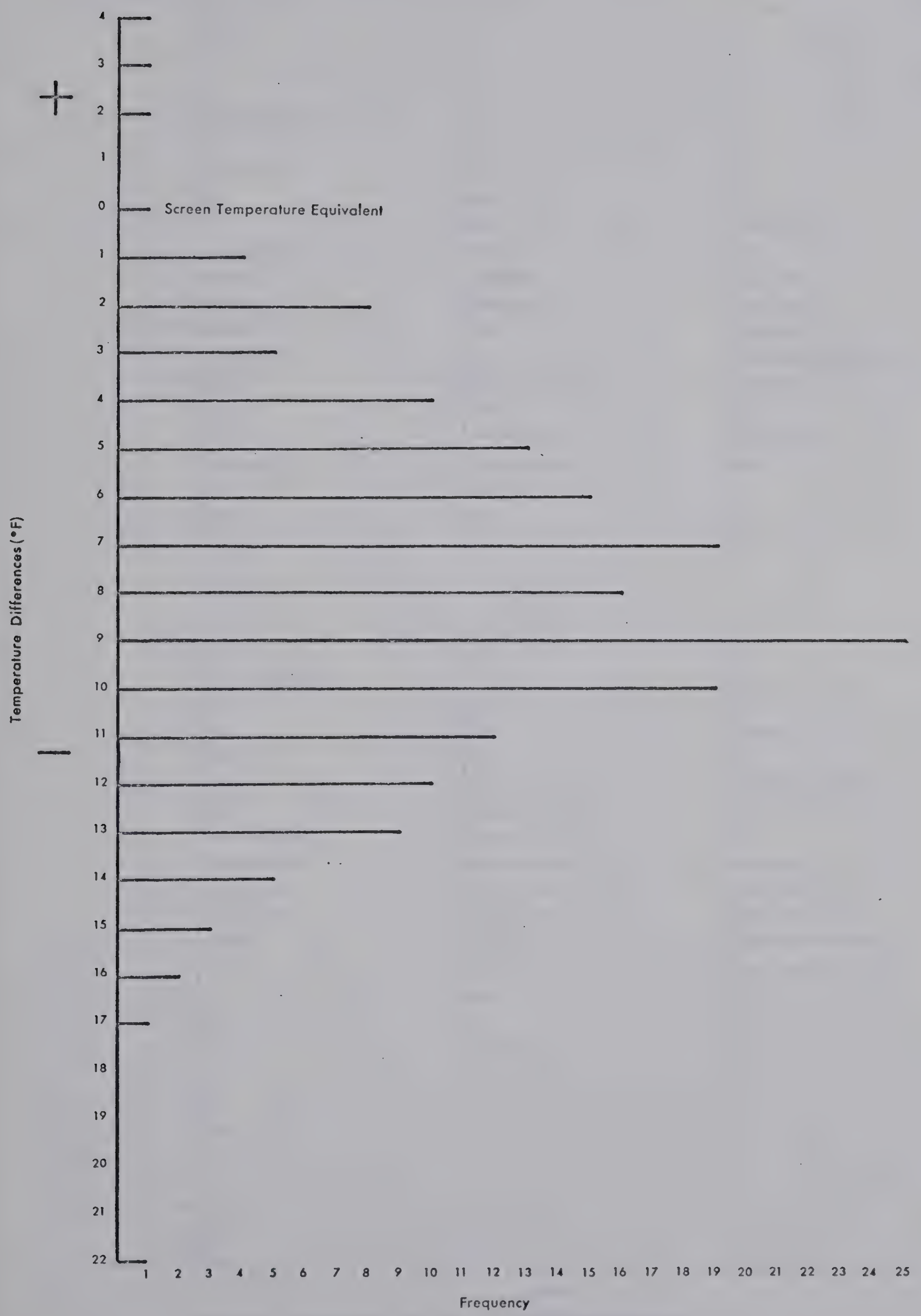
Table 2.1 Mean Minimum and Mean Grass Minimum: Beaverlodge May - October, 1968

	May	June	July	August	September	October
Mean Min. ^{o}F	36	43	47	43	39	31
Mean Grass Min. ^{o}F	28	34	39	35	31	24
Difference ^{o}F	8	9	8	8	8	7

Source: Daily Agrometeorological Data, 1968, v. 4, nos. 5-10, Department of Transport, Meteorological Branch.

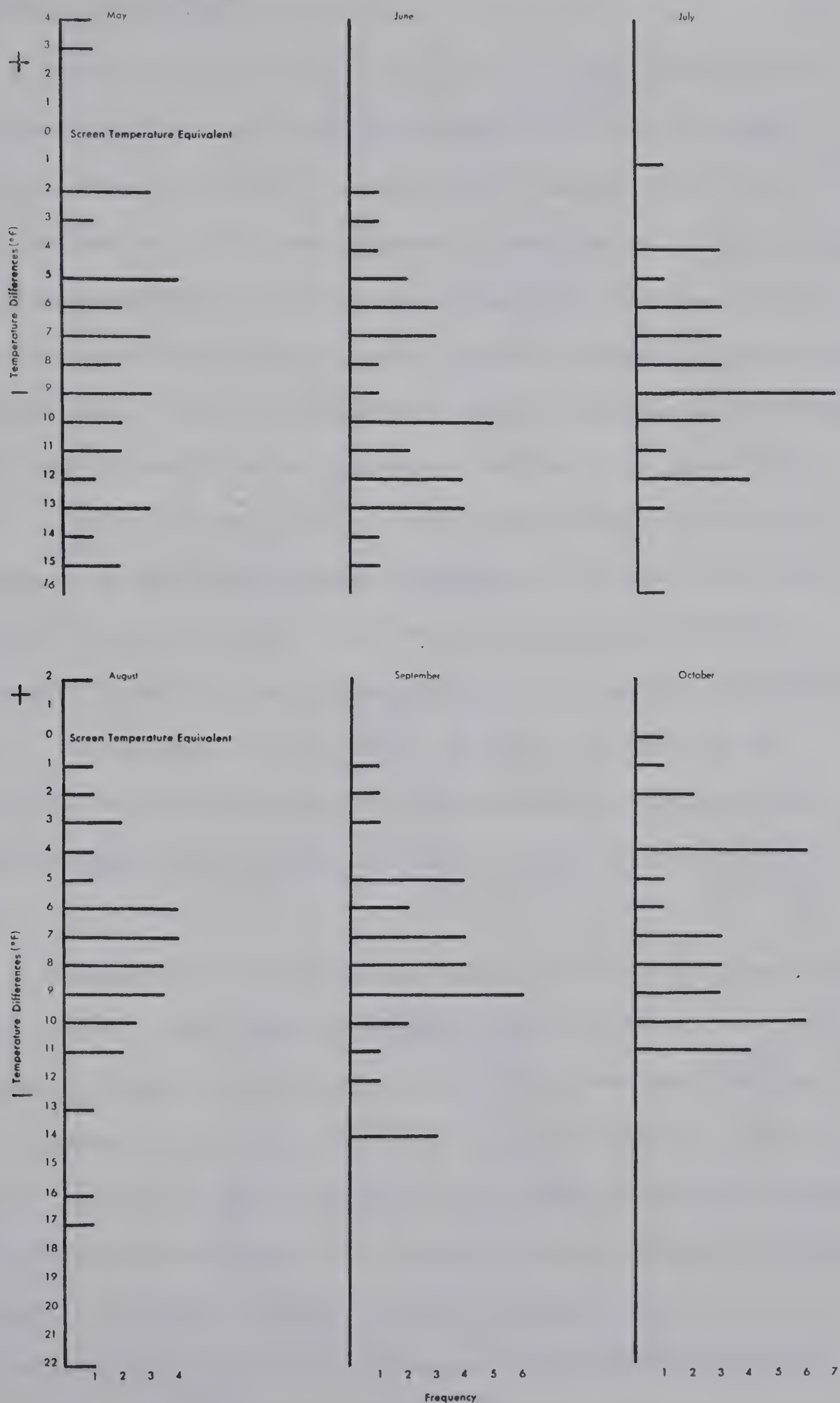
This substantiates Longley's observations that, "a ground frost can occur in the vicinity of the screen when the screen temperature never drops below $40^{o}F$" (Longley, 1967, p. 1), although, of course, such a frost may not have a direct damaging effect upon crops. In terms of the daily frequency of occurrence about the mean, the data, whilst not showing a perfectly normal distribution, are strongly clustered around the mean for each of the months (Fig. 2.2) and for the period as a whole (Fig. 2.1). For the whole period 77% of the data occur within 4 degrees F of the mean, with the result that the standard deviation of the distribution is relatively small and less than four (Fig. 2.2). The extreme difference occurs in August and amounts to 22 degrees F. The ground level readings record 16 frosts in July and August with temperatures as low as $22^{o}F$, whilst readings from the screen did not record a single frost. On only three occasions did the ground thermometer record a higher temperature. This is considered to be significant evidence validating the viewpoint that $32^{o}F$ provides

Temperature Differences between Screen Minimum and Grass Minimum Beaverlodge May-October 1968



Source: Daily Agrometeorological Data, 1968, v.4, nos.5-10, Dept. of Transport, Meteorological Branch.

Temperature Differences between Screen Minimum and Grass Minimum by Individual Months Beaverlodge May—October 1968



Source: Daily Agrometeorological Data,1968,v.4,nos.5-10,Dept.of Transport, Meteorological Branch.

a meaningful criterion for defining the frost-free season with reference to agriculture.

The next stage, given 32°F as the critical threshold value, is to define some minimal frost-free period sufficient to enable successful cereal cultivation. Reed (1916), Bennett (1959), and Leonard and Martin (1963) have suggested a mean period of 90-100 days as the absolute minimum and this will be accepted for this study. In fact wheat grown in northeast Alberta frequently takes 100 days and usually 110 days. Oats also generally require approximately 100 days and only certain varieties of barley can regularly be grown within 100 days. Tables 2.2 and 2.3 list the average length of the frost-free season, the killing frost-free season and the respective dates for the last spring and first fall frost for the period 1959-68. Median values have also been calculated for the same data (Tables 2.4 and 2.5). The median gives the exact 50% level of risk but the difference between the average and median values is minimal, the implication being that the mean can also be taken as the 50% level of risk.

Considering the average and median values based upon 32°F, only two stations, Cold Lake and Meanook, record a frost-free period significantly longer than 100 days, while three stations, Newbrook, Vilna and Rochester, are well below the required minimum. Athabasca, Elk Point, Iron River and Lac La Biche all record frost-free seasons between 101 and 106 days and are therefore scarcely above the minimum. These frost-free periods become even more marginal when it is considered they constitute only average or median values, and thus there is only a 50% chance of a frost-free season as long, or longer.

Table 2.2 Frost-Free Season 1959-68, Average Values

	Frost-Free Period	Average date of last Spring frost	Average date of first Fall frost
Athabasca	106	May 27	September 10
Meanook	124	May 17	September 18
Rochester	73	June 13	August 25
Newbrook	67	June 14	August 20
Lac La Biche	101	June 1	September 10
Vilna	75	June 14	August 28
Iron River	105 (78)	May 23 (June 10)	September 7 (August 27)
Cold Lake	117	May 23	September 17
Elk Point	105 (70)	May 26 (June 13)	September 8 (August 22)

Source: Department of Transport, Meteorological Branch, Monthly Records, 1959-68.

Figures in brackets are for the 1931-60 period, Source: Climatic Normals, Volume 6, Frost Data, Canada, Department of Transport, Meteorological Branch, 1968, p. 4.

Table 2.3 Killing Frost-Free Season 1959-68, Average Values

	Killing Frost-Free Period	Average date of last Spring frost	Average date of first Fall frost
Athabasca	134	May 9	September 20
Meanook	150	May 7	October 4
Rochester	120	May 19	September 16
Newbrook	109	May 24	September 10
Lac La Biche	131	May 13	September 21
Vilna	109	May 26	September 12
Iron River	131	May 13	September 21
Cold Lake	139	May 12	September 28
Elk Point	124	May 16	September 17

Source: Department of Transport, Meteorological Branch, Monthly Records, 1959-68.

Table 2.4 Frost-Free Season 1959-68, Median Values

	Frost-Free Period	Median date of last Spring frost	Median date of first Fall frost
Athabasca	112	May 21	September 10
Meanook	120	May 16	September 13
Rochester	72	June 22	September 2
Newbrook	65	June 22	August 26
Lac La Biche	107	May 26	September 10
Vilna	70	June 23	September 1
Iron River	107	May 22	September 5
Cold Lake	120	May 19	September 15
Elk Point	109	May 23	September 9

Source: Department of Transport, Meteorological Branch, Monthly Records, 1959-68.

Table 2.5 Killing Frost-Free Season 1959-68, Median Values

	Killing Frost-Free Period	Median date of last Spring frost	Median date of first Fall frost
Athabasca	131	May 10	September 18
Meanook	149	May 9	October 5
Rochester	121	May 18	September 16
Newbrook	110	May 21	September 9
Lac La Biche	135	May 13	September 25
Vilna	105	May 26	September 9
Iron River	136	May 12	September 25
Cold Lake	142	May 11	September 30
Elk Point	127	May 16	September 20

Source: Department of Transport, Meteorological Branch, Monthly Records, 1959-68.

The risk involved for the farmer is increased by the impossibility of being able to predict, in any one year, either the length of the frost-free season or the dates of the last spring or first frost.

There is, in fact, considerable variation in the length of the frost-free season from year to year. It is possible in any given year for the last spring frost to occur relatively early and the first fall frost to occur relatively late, or vice versa. As a result, frost-free seasons of 23 days (Newbrook) and 151 days (Cold Lake) have been recorded during the last ten years within northeast Alberta. Some simple statistical tests illustrate these points. The standard deviation of the frost-free period summarises the variations about the mean within the limits of one standard deviation. Given a normal distribution, the probability of a value differing from the average by less than one standard deviation is 66%. It must be realized, however, that standard deviations calculated for as short a period as ten years have only limited value. Spearman's rank correlation technique is used here to test the hypothesis that an early spring frost is accompanied by an early fall frost and a late spring frost by a late fall frost. It is, therefore, a test of the predictability of fall frosts given the date of spring frosts. To use Spearman's rank correlation technique for the period 1959-68, both spring and fall frosts are ranked in their relative order of occurrence. To obtain the rank correlation the formula $1 - \frac{6 \ D^2}{N \ (N^2-1)}$ is used, where D is the difference in ranks for each year and N is the number of occurrences which in this case is ten (Spiegler, 1961, p. 246). In common with meteorological practice, July 15 is taken as the date dividing

spring and fall. With the exception of Elk Point, the results are noteworthy for the extremely large standard deviations and virtually non-existant rank correlation coefficients.

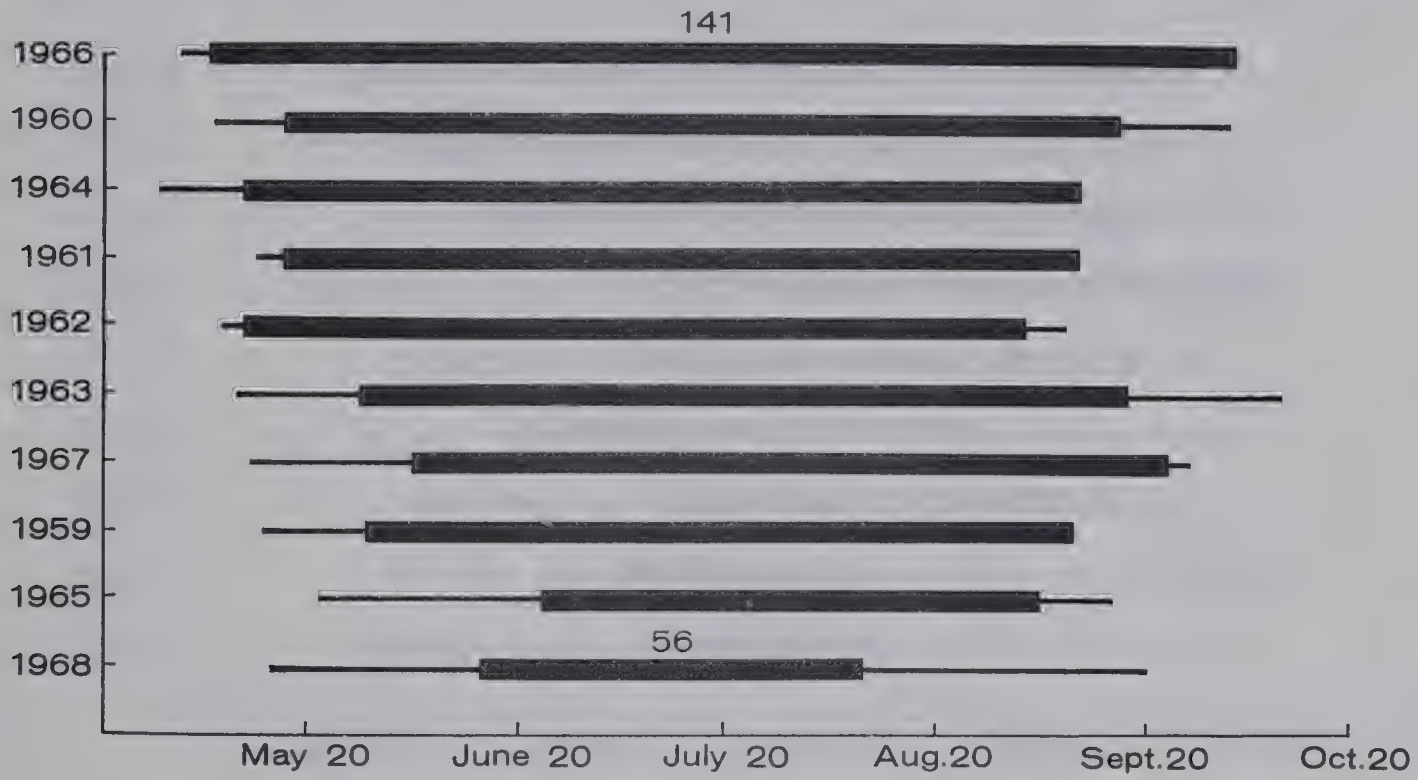
Table 2.6 Statistical Indexes for the Variability and Predictability of Frost

	Means (Frost-free days)	Standard Deviation	Rank Correlation Coefficient
Athabasca	106	23	-.20
Meanook	124	13	-.15
Rochester	73	27	.30
Newbrook	67	23	.10
Lac La Biche	101	19	.18
Vilna	75	23	-.48
Iron River	105	11	.13
Cold Lake	117	20	.05
Elk Point	105	9	.76

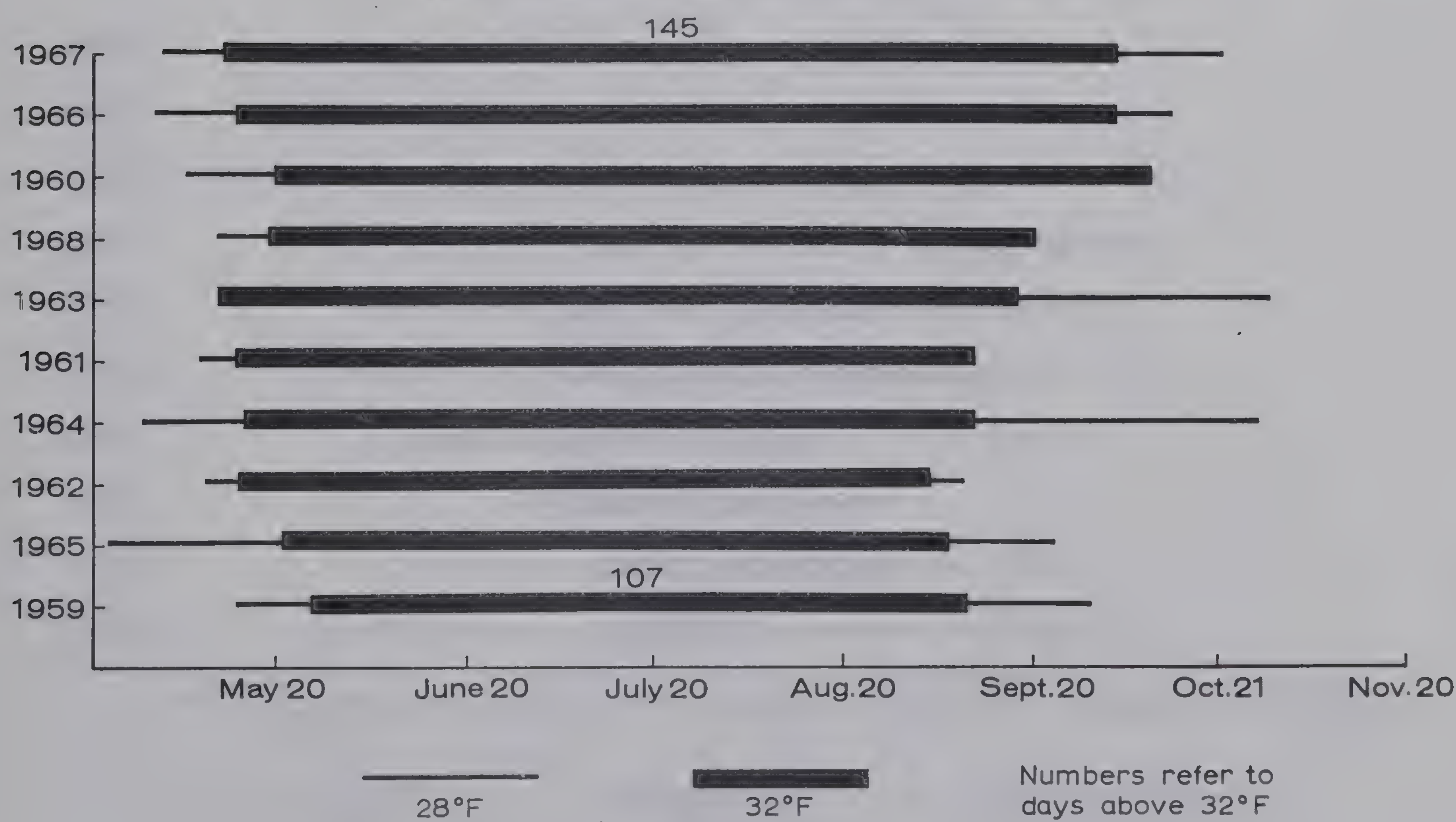
Figures 2.3 - 2.11 show for each of the nine stations the relationship between the frost-free season and the killing frost-free season, and the variation in the lengths of these seasons for the 1959-68 period. The seasons are ranked according to length (32°F) so that the shortest is at the bottom of the diagram and the longest at the top, with the actual number of days given for these extreme situations. It will be noted that longevity or shortness of the frost-free season based upon 32°F does not necessarily imply the same for the killing frost-free season. These diagrams illustrate quite clearly the shortness of the frost-free period and its large variation from year to year, and hence its unpredictability.

FROST FREE SEASON

ATHABASCA 1959–1968 Figure 2.3

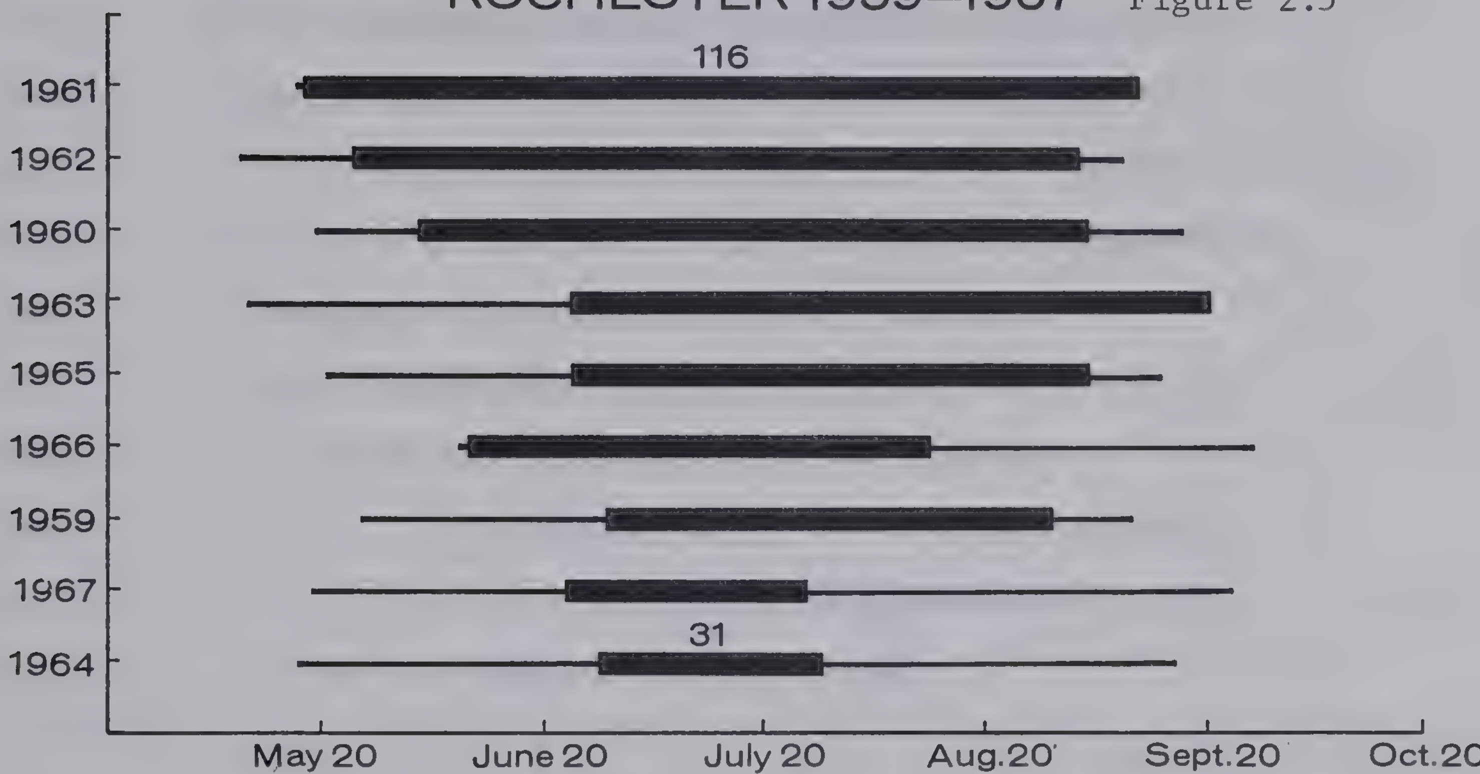


MEANOOK 1959–1968 Figure 2.4

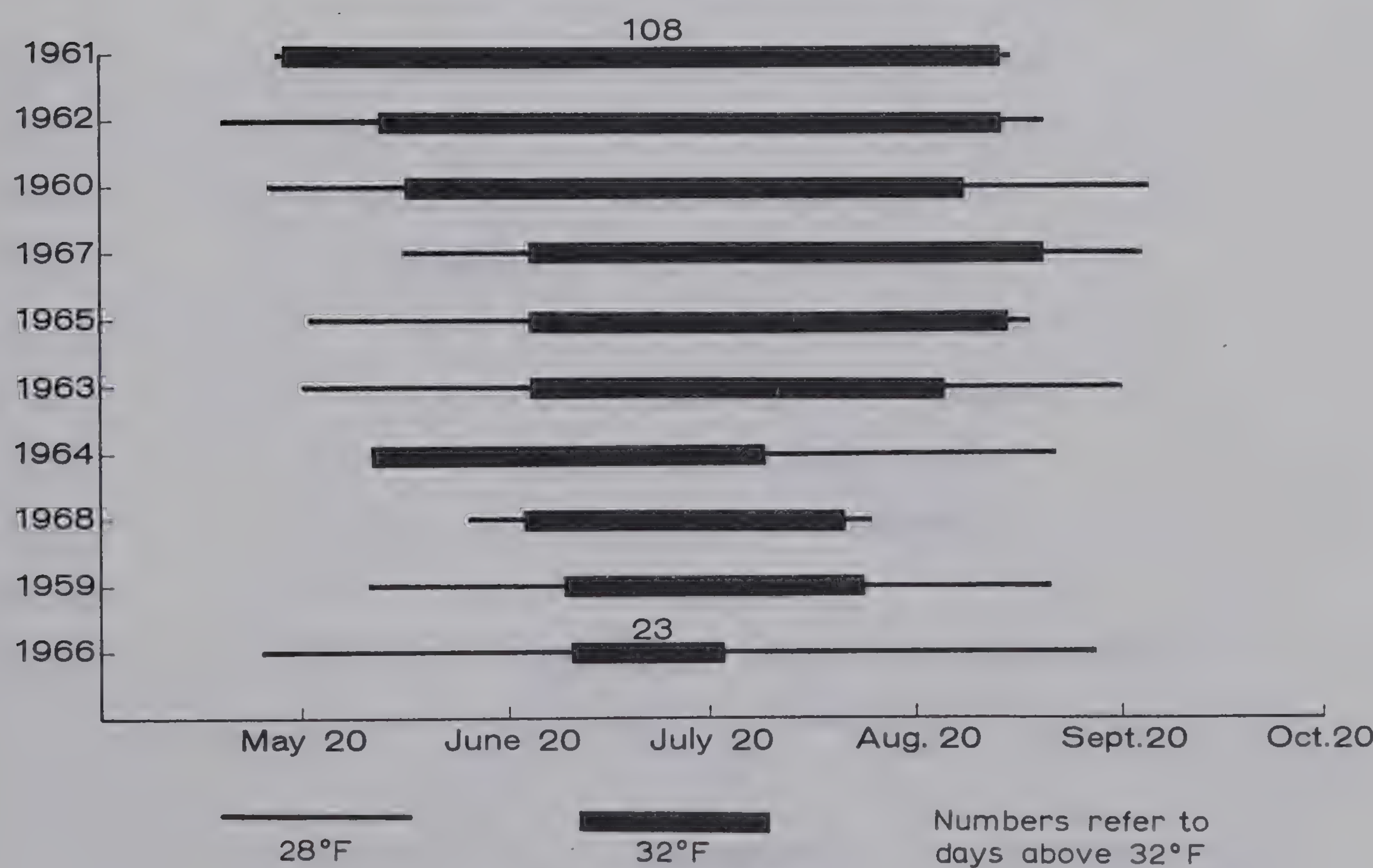


FROST FREE SEASON

ROCHESTER 1959–1967 Figure 2.5

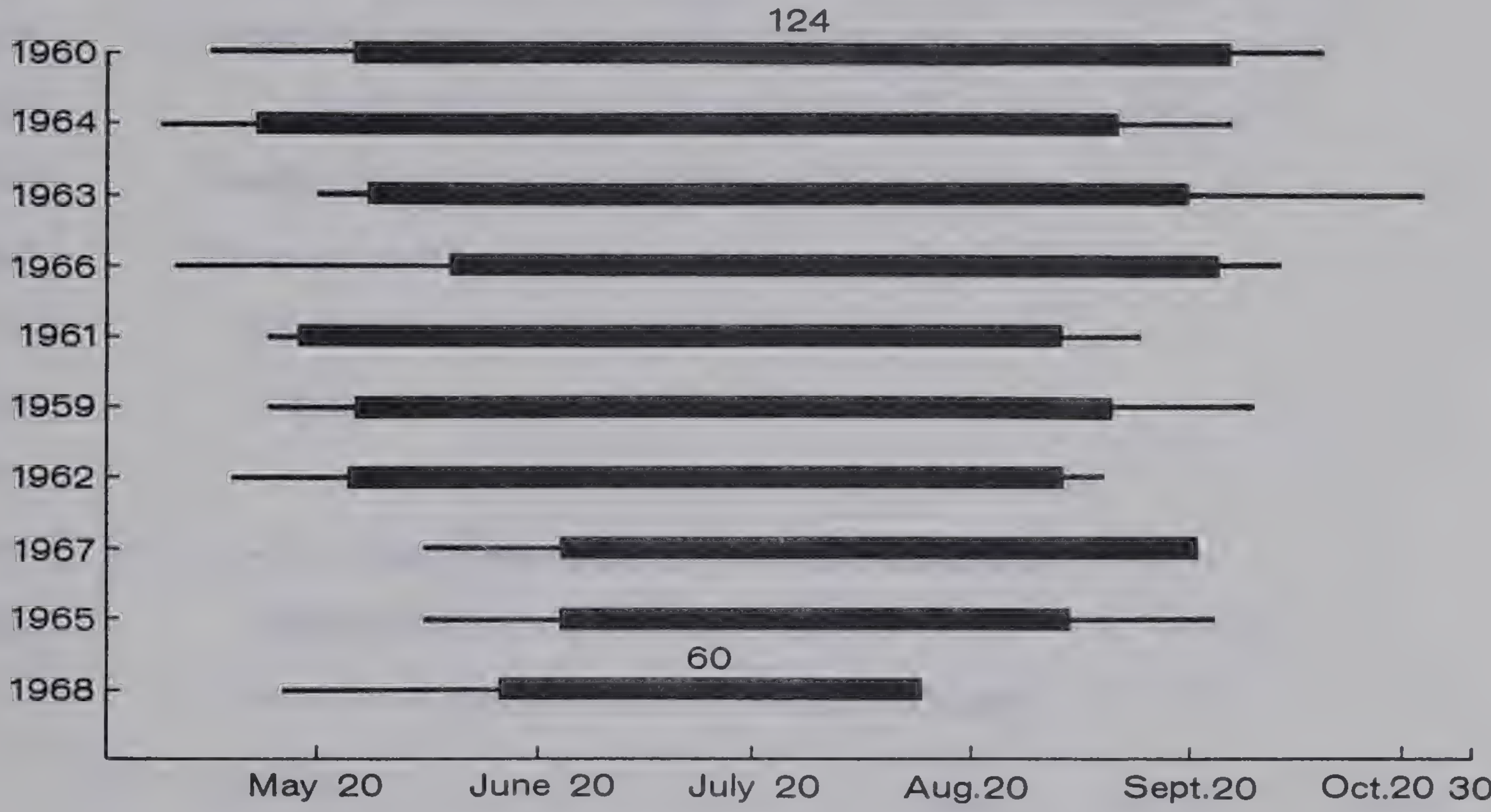


NEWBROOK 1959–1968 Figure 2.6

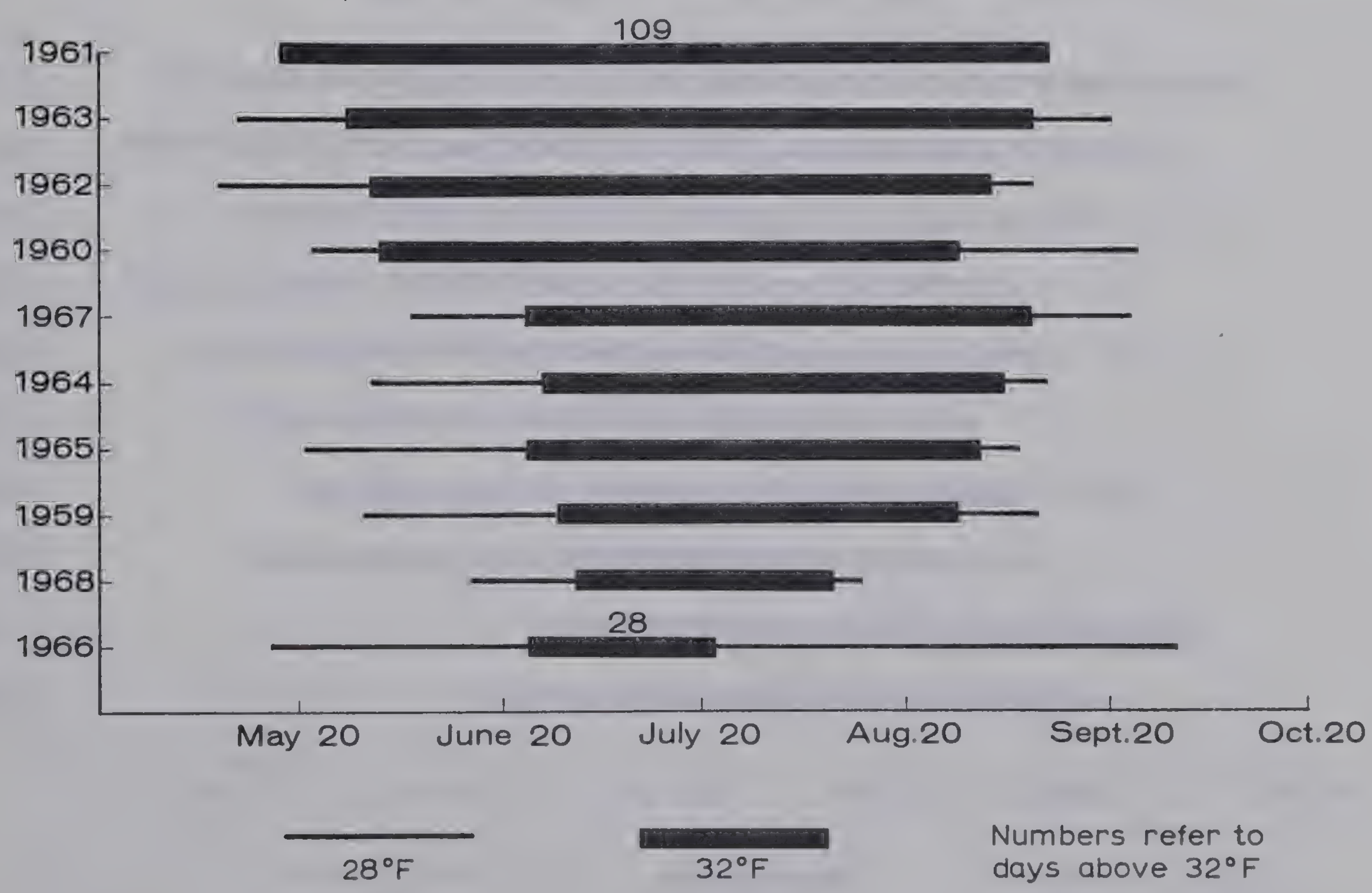


FROST FREE SEASON

LAC LA BICHE 1959–1968 Figure 2.7

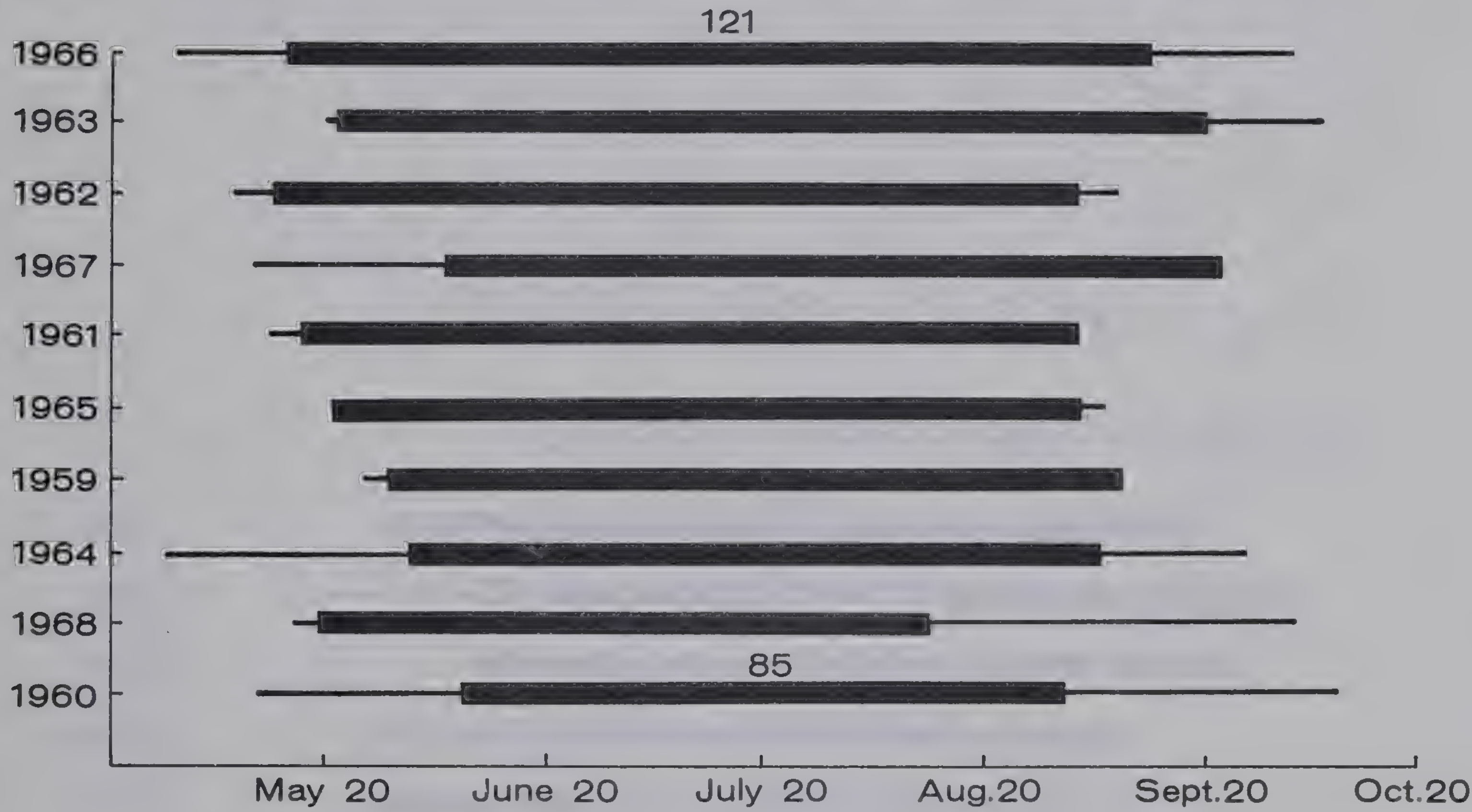


VILNA 1959–1968 Figure 2.8

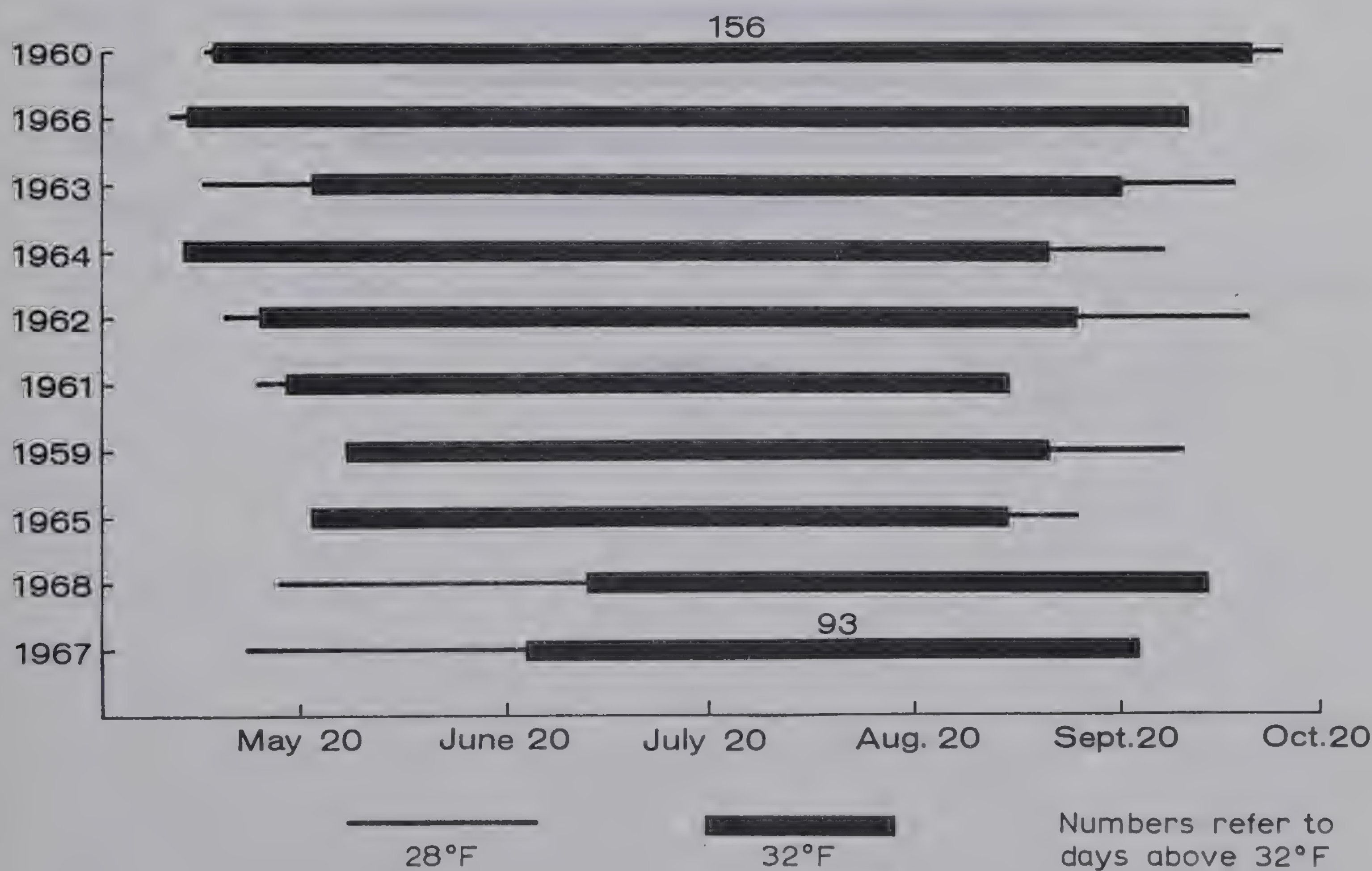


FROST FREE SEASON

IRON RIVER 1959–1968 Figure 2.9

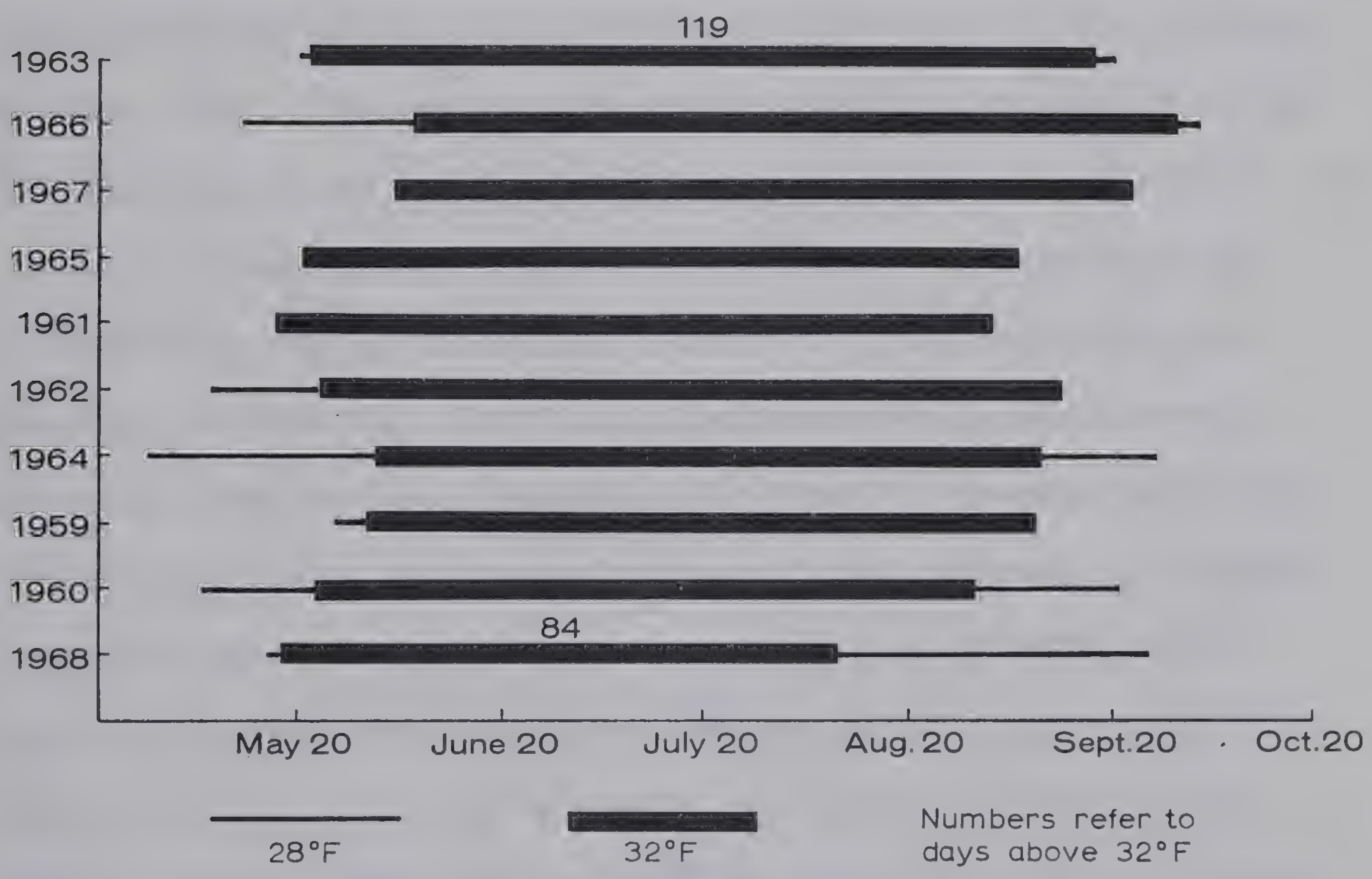


COLD LAKE 1959–1968 Figure 2.10



FROST FREE SEASON

ELK POINT 1959–1968 Figure 2.11



Despite the difficulties, several attempts have been made to predict the occurrence of frost both seasonally and at the forecast level. Fraser (1966) has suggested as a climatological hypothesis that greater than average rainfall in May was highly correlated with an absence of frosts in June (Fraser, 1966). From an analysis of the temperature records from 1883 to 1965 at Winnipeg, he suggested that heavier than normal May rain reduced the risk of frost in June as a result of storage of water in the soil and the subsequent retardation of nocturnal cooling. Another formula for predicting minimum temperatures was developed at the R.C.A.F. station, Penhold, Alberta (Korven, 1964). The minimum temperature for the night was calculated from the temperature and dew point temperature spread at 1700 hours and the rate of cooling from 1700 hours to sunrise. Between April and September the average difference between the predicted and actual overnight low was 2°F. The formula was only applicable however, for calm, clear weather conditions. For similar synoptic conditions O'Neill developed a rather more accurate formula whereby the minimum temperature was calculated to the nearest degree (O'Neill, 1968). Kagawa in an evaluation of Brunt's cooling formula, again ignoring advection frosts, was able to predict the minimum temperature for Edmonton within a mean error of 2.3°F by using such variables as soil density, specific heat, the nocturnal amount of outgoing terrestrial radiation and the coefficient of thermal conductivity in order to determine the temperature decrease from sunset to sunrise (Kagawa, 1968).

Ventskevich has reviewed several other techniques for frost forecasting (Ventskevich, 1936, pp. 143-145). The Braunov method related the probability of frost to the absolute temperature in the

evening. The lower the temperature at 9 p.m. and the greater the difference between the temperature at 1 p.m. and 9 p.m., the greater the probability of frost. Another technique reviewed by Ventskevich is the dew point method which simply states that if the dew point is below 2°C at 9 p.m., frosts may be expected. Mikhelson considers the risk of frost as a function of atmospheric vapour and based his technique of forecasting on the assumption that the lower the absolute humidity of air the greater the probability of frost. By and large, however, frost forecasting has remained a part of the general synoptic analysis issued by meteorological stations. Unfortunately the prediction of frost occurrence during the growing season before the season has started has been beyond the scope of meteorological forecasters. Advance warning of frost is usually at the most 24 hours and this, of course, has little value for grain farmers once their crop has been planted. For the time being at least frost forecasting must remain a part of the daily weather bulletin.

The variation and lack of predictability of the occurrence of frost and in the length of the frost-free season imparts a considerable risk to the farmer on the northern margin of cultivation. As such the mean and standard deviations are useful in that they show the chance of frost and the length of the frost-free season at the 50% level of risk, and an index of variability and this level. Although the farmer may wish to operate at a less than 50% risk level, the records from three stations, Newbrook, Rochester, and Vilna, indicate there were just not enough frost-free days during the period 1959-68 to grow cereal crops even at this probability level (Table 2.3). According to Reed and Tolley (Reed

and Tolley, 1916, p. 354) a farmer should plan to grow his crops at a risk level no greater than 20% and this figure includes the risk of both spring and fall frosts. At this level of risk only the Meanook station records a frost-free season greater than 100 days whilst all the others record a frost-free season below 90 days (Table 2.7). The long term records included in this table for Elk Point and Iron River suggest a much greater level of frost risk. The probability figures for the 1959-68 period were calculated rather generously by taking the day after the second latest frost in spring and the day before the second earliest frost in the fall.

Table 2.7 Dates of Frost and Length of the Frost-Free Season, 1959-68, at the 20% Level of Risk*

	Spring	Fall	Frost-Free Season (days)
Athabasca	June 15	September 1	78
Meanook	May 21	September 5	107
Rochester	June 27	August 8	42
Newbrook	June 28	August 8	41
Lac La Biche	June 23	September 1	71
Vilna	June 29	August 8	40
Iron River	June 7 (June 25)	August 31 (August 7)	84 (43)
Cold Lake	June 23	September 2	72
Elk Point	June 5 (June 29)	August 30 (August 6)	85 (38)

Figures in brackets are for 1931-60 period, Source: Climatic Normals, Volume 6, Frost Data, Canada, Department of Transport, Meteorological Branch, 1968.
* 20% level of risk = 10% spring risk + 10% fall risk.

It is obvious that the farmer in northeast Alberta cannot plan his operations, if he is to grow cereal crops at the 20% level

of risk. Taking the median dates in spring (Table 2.4), three stations record frosts in late June, and with average values four stations record June frosts (Table 2.2). In the fall average values occur within August three times and median values once. However the very latest median value is only September 15 (Cold Lake) and the latest average value, September 18 (Meanook). For northeast Alberta as a whole spring frosts should be expected on the average between mid-May and late June, and in the fall between late August and mid-September. Even using 28°F criteria an average or median does not occur before May 7 and only one station (Meanook) records an average and median fall frost in early October. Considering only the most favourable temperature records (i.e. the Cold Lake and Meanook stations), killing frosts should be expected in most years in the first two weeks of May and in the latter half of September (Table 2.3).

The maximum variation in the length of the frost-free period between stations is 57 days, and 41 days for the killing frost-free period. The possibility of determining regional differences within the study area is debateable, however, because the stations may not be very representative of the surrounding area. In fact the variations between years at individual stations 1959-68, are greater than the average variation between the stations. Difficulties in mapping frost occurrence arise, not only because of variations through time, but because of variations through space, some of which can be extreme over a relatively short distance, as discussed in the next chapter. Although minimum temperatures are broadly a function of latitude, altitude and distance from the sea, within any region the micro-climatic variations may be considerable.

The variations in the frost records of the study area are predominantly the result of these micro-climatic factors. Computations of averages, representative of an area, from temperature records may also be 'distorted' by climatic cycles. Longley, by a comparison of frost-free periods and an analysis of running minimum temperature means for selected stations within Alberta, has distinguished a definite warm cycle for the period 1951-64 in most parts of Alberta (Longley, 1967).

Average increases for this period in the lengths of the frost-free period for northern Alberta were 19 days. The causes and mechanics of such cycles are not clear. Indeed there are considerable difficulties in assessing its magnitude. For example, the actual extent of the increase in the frost-free season may be attributable to both the warming cycle, and to micro-climatic factors affecting the readings of instrument shelters. Longley, however, did show a strong correlation between minimum temperatures and frost-free season. Where the mean minimum temperature increased in the spring and fall, so did the frost-free season, and where the minimum temperature remained the same, so did the frost-free season. Such changes are obviously important to farming in marginal areas because very small changes in the mean minimum temperature (for example 1 or 2 degrees) are reflected by a considerable difference in the frost-free period (Longley, 1967, p. 247). It is in Professor Longley's opinion that the warm cycle that he identified between 1951-64 has now ended (Pers. Comm., May 1970).

Various authors have attempted some form of mapping

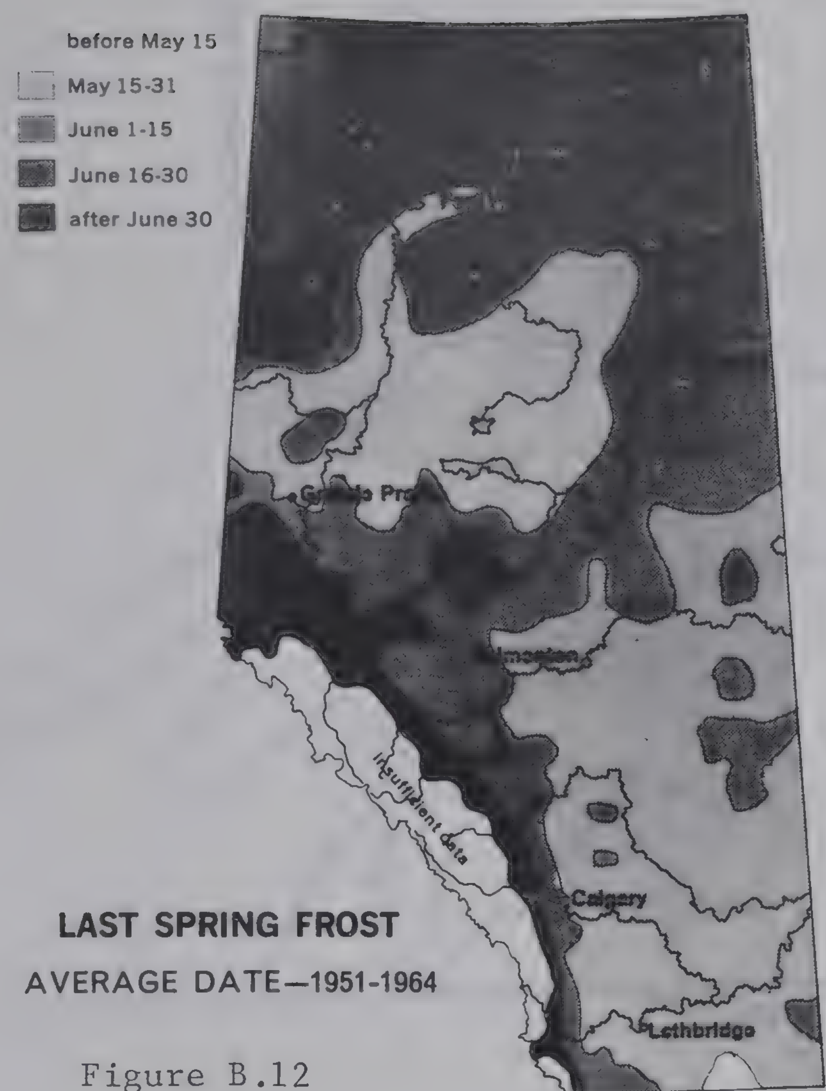
regional differences in the frost hazard (Fig. 2.12-2.18), despite the problems of interpolating minimum temperature data. Three intrepretations shown here of the regional distribution of the frost hazard are based upon climatological statistics for 1921-50 (Currie), 1931-60 (Chapman and Brown) and 1951-64 (Longley). Table 2.8 illustrates the approximate average frost-free period and spring and fall dates for northeast Alberta by the same three meteorologists.

Table 2.8 Frost-Free Seasons Derived for Northeast Alberta

Longley 1951-64	Currie 1921-50	Chapman and Brown 1931-60
107	89	77
June 1 - September 15	June 1 - August 28	June 15 - August 31

Source: Hozack, 1969, p. 24.

Longley's maps (Figs. 2.12-2.14) are the most detailed and indicate the extremely low values for Rochester, Vilna and Newbrook, especially the maps showing the last spring and first fall frosts. According to Longley these stations appear to be on the eastern edge of a frost hazardous area, demarcated by the 80 day frost-free isoline, which appears not to be drawn quite far enough to the south-east (Fig.2.14). The difficulty, of course, is the extremely high value of Meanook within the same area. Also the Newbrook and Rochester temperatures were not used because these stations had not been operating for sufficiently long. For the most part Longley suggests that the 100-day frost-free isoline encompasses much of the rest of the study area, with the northeastern margin from Lac La Biche to Cold Lake enjoying relatively late fall frosts.



LAST SPRING FROST

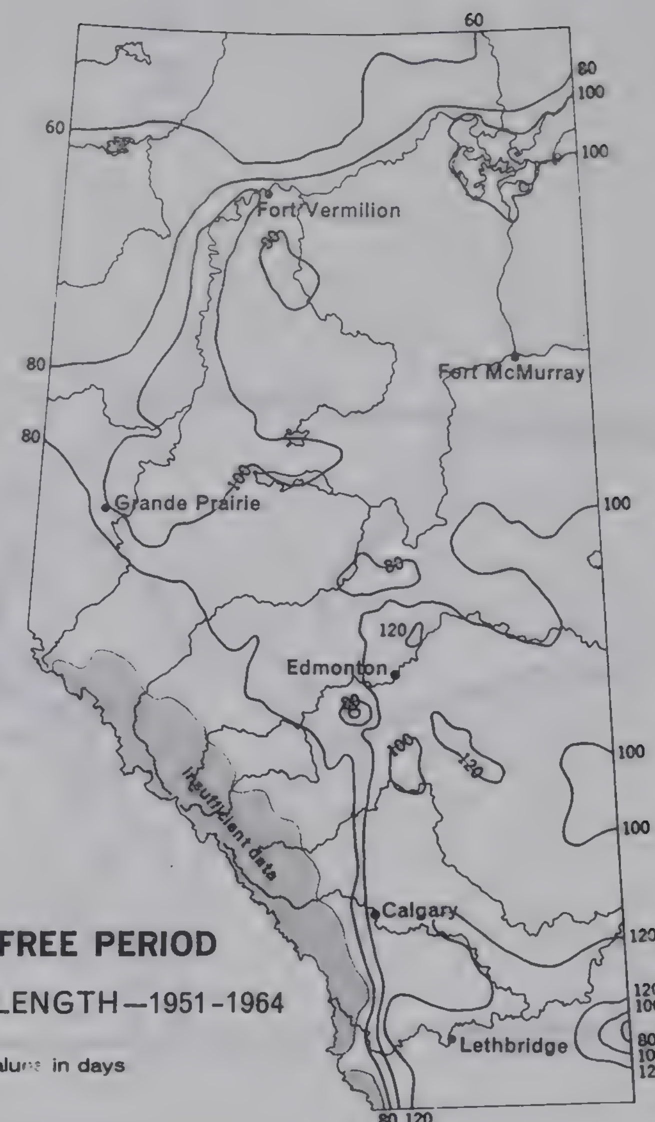
AVERAGE DATE—1951-1964

Figure B.12

FIRST FALL FROST

AVERAGE DATE—1951-1964

Figure B.13



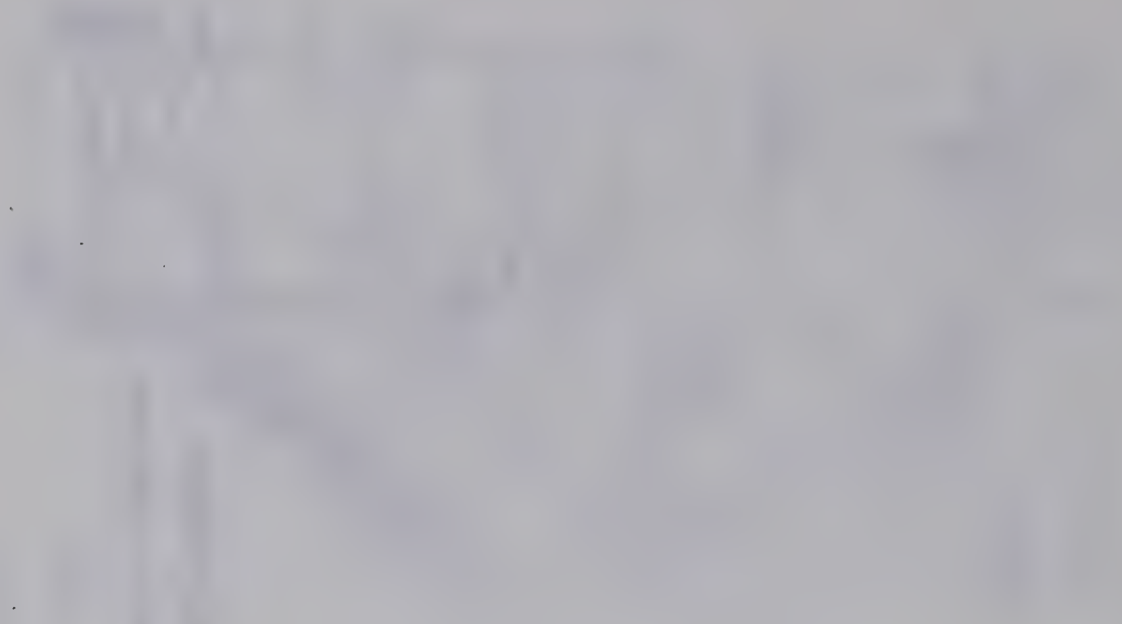
FROST-FREE PERIOD

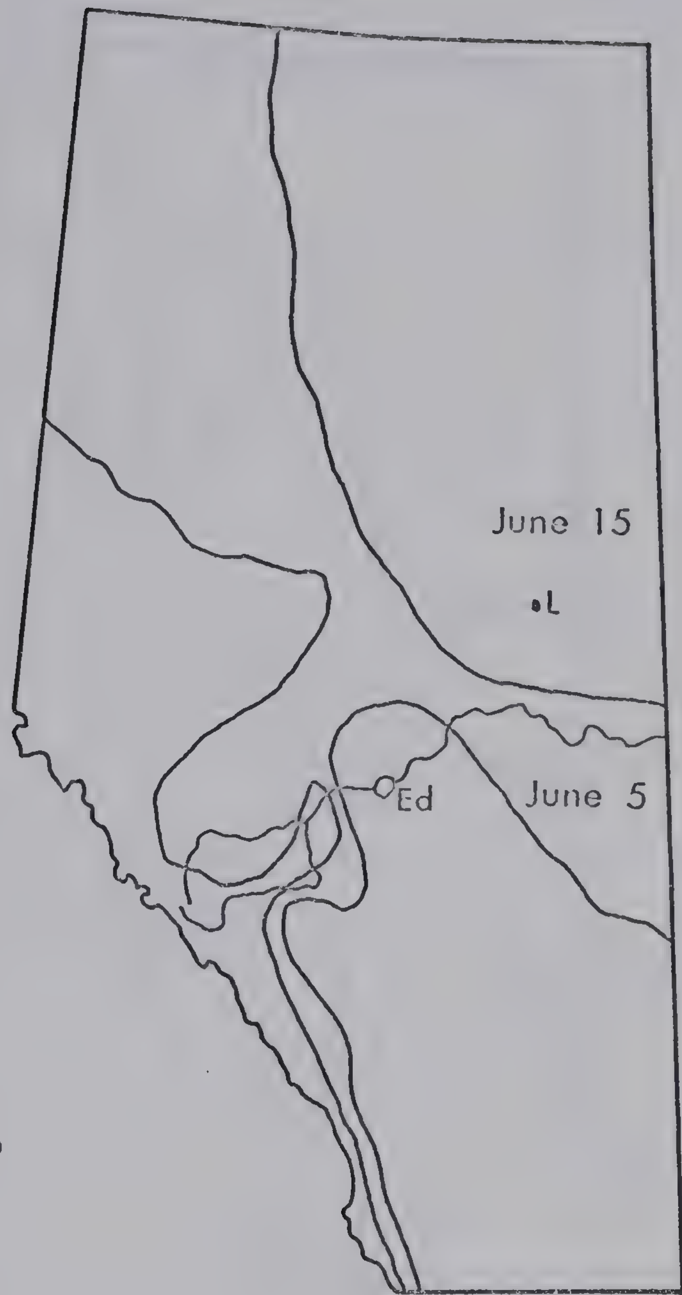
AVERAGE LENGTH—1951-1964

Values in days

Figure B.14

Source for all figures, Longley, 1968.





Last Spring Frost

Average date 1931-60

Figure 2.15

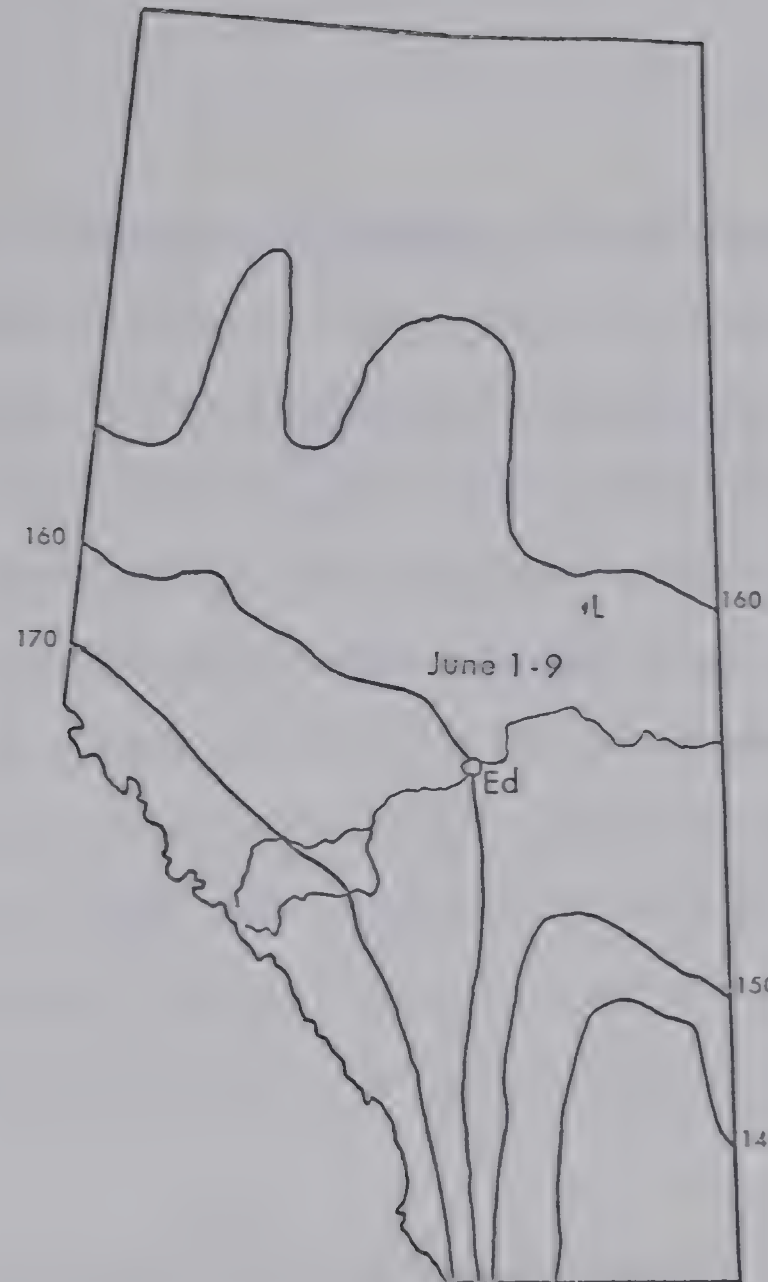
Source: Chapman and Brown, 1966

First Fall Frost

Average date 1931-60

Figure 2.16

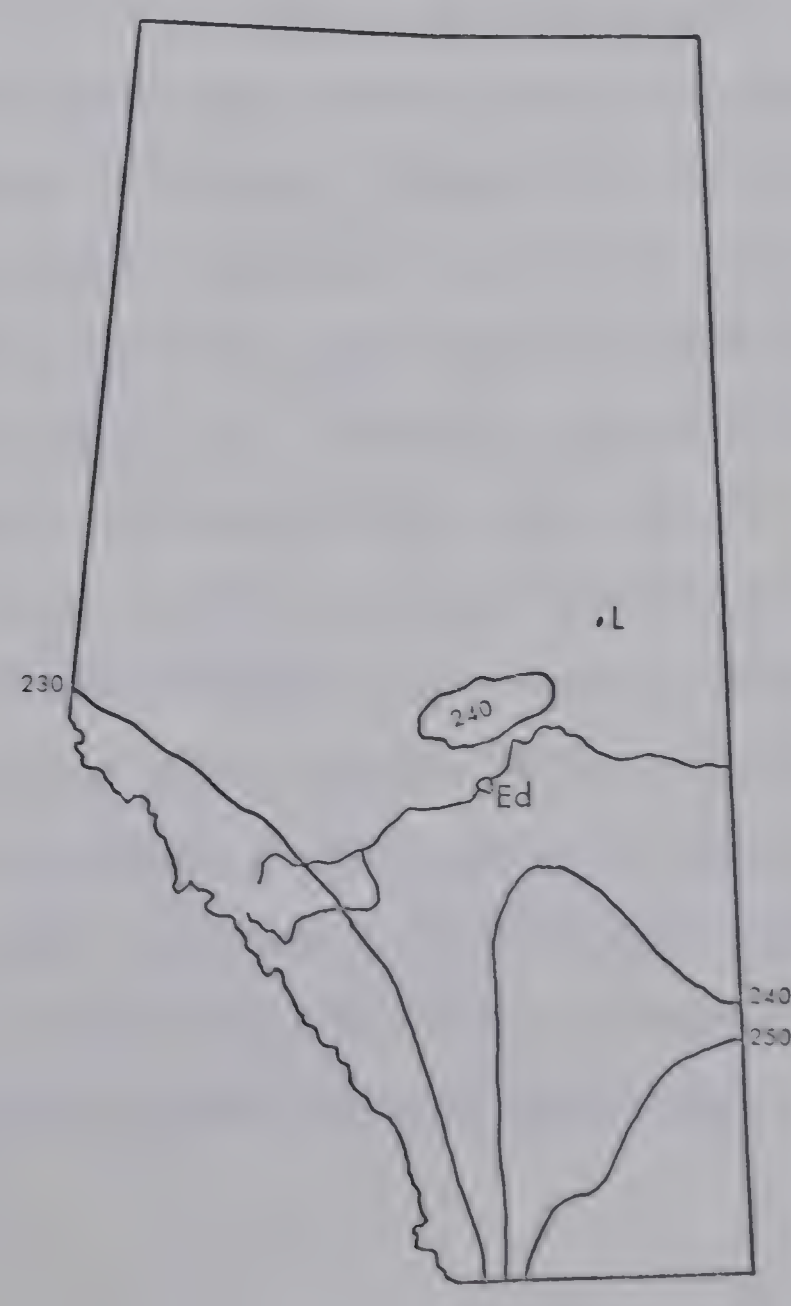
Source: Chapman and Brown,1966



Isolines for median number of days from the beginning of the year to the last day in spring with frost.

Figure 2.17

Source: Currie, 1959



Isolines for median number of days from beginning of the year to the first day in fall with frost.

Figure 2.18

Source: Currie,1959

The other maps by Currie, and Chapman and Brown are more general and tend to reflect the broad climatic zones of Alberta. As a result the isolines slope in a NW-SE direction. Chapman and Brown, for instance, feel the northeastern margin receives relatively earlier fall frosts (and later spring frosts) than the areas to the south. These authors indicate that the entire study area fall below the 80-day frost-free isoline, although they find this isoline particularly hard to draw because of micro-climatic variations (Chapman and Brown, 1966, p. 9). Currie differs from this interpretation only in that the 80-day frost-free isoline is pushed slightly beyond the margins of the study area. According to Currie northeast Alberta receives 80-90 days frost-free.

Differences in the maps can be partly attributed to the different time periods involved. Longley not only covered a shorter period during which warm trends were evident, but also utilised the records of a larger number of stations. However, for the greater part of the study area, Longley and Currie agree on the average date of the last spring frost, and Currie, and Chapman and Brown agree on the date of the first fall frost. Grouping their results together, frosts should be expected, on average between early and mid-June and between late August and mid-September, which is virtually the same conclusion reached previously (page 51) in the analysis of the records of the nine stations for the 1959-68 period. Currie, and Chapman and Brown do not detect any regional variations and assess northeast Alberta as having a similar frost hazard whilst Longley allows for more variation in the average frost-free season. These maps provide a useful regional framework for more detailed local studies. All

authors, however, are aware of the difficulties of mapping regional frost isolines.

> "When one couples with the variation caused by local characteristics, the variations from year to year, and the variation caused by a changing temperature, one must recognise that frost records from the past are useful as guides, but only when the use is made with caution" (Longley, 1967, p. 249).

Accepting that an average frost-free period of 100 days or less indicates marginal temperature conditions for the growth of cereal crops, and that the meteorological records of point locations are representative at a regional level, the study area, whether on the basis of Longley's, Currie's or Chapman and Brown's criteria, or on the meteorological record for 1959-68, must be judged to be at the absolute limit, or even beyond, for successful cereal cultivation. Indeed Currie, and Chapman and Brown would place the study area beyond this limit. Whether or not the frost-free season by itself is a suitable index of marginality depends to a large extent on the sufficiency of other physical requirements for plant growth within the limits of the frost-free season. A discussion of these other requirements follows.

The Growing Season

The growing season is that period when the mean temperature is above 42°F, and for the study area this is usually May to September inclusive, on the basis of average monthly temperatures. There are differences of opinion as to the exact value of this temperature but it is usually taken as somewhere between 39°F and 43°F for spring

sown cereals. Carder (1965a), Hozack (1969), Chapman and Brown (1966), Symons (1967), and Boughner (1964) all use 42°F, Gregory (1954) suggests 42.8°F, Unstead (1912) 41°F, while Leonard and Martin (1963) regard 39.2°F as the critical minimum. In line with most other studies in Canada, 42°F will be accepted in this study as the base minimum temperature required by spring-sown cereals for growth. Within the limits of the growing season it is necessary to evaluate the availability of heat, in association with the factors of photoperiodism, and moisture for plant growth.

The Degree Day Concept

In order to assess the quantity of heat available for plant growth a concept known as degree days, or accumulated temperature, has been developed. "This [the degree day concept] provides a measure of intensity of growth and this is just as significant a parameter as sheer length of growing season" (Taylor, 1967, p. 18). Within the limits of the growing season the base temperature of 42°F is subtracted from the daily mean temperature and the results are summed in order to give the total number of degree days, or accumulated temperature, for the growing season.

Considerable criticism has been levelled at the concept of degree days as an adequate expression of the relationship between temperature and plant growth. These criticisms have attacked the basic premises of the concept and have shown many of them to be erroneous. For example, no account is taken of day length; the theory assumes only one base temperature in the life of a plant; a linear relationship between plant growth and accumulated temperature does

not exist, and the theory assumes that other meteorological variables do not influence the quantity of heat required for growth (Boughner, 1964, p. 3). In short, the degree day concept has no theoretical justification and is much too simple to account for plant growth given the complicated nature of plant physiology. However, results have been shown to have empirical value in identifying broad regional differences in ecological variations, and in particular in defining minimal temperature amounts required by various plants.

"It would seem in fact, that if accumulated temperature has any significance and value, it lies in its definition of the minimum temperature conditions of growth of particular plant species, whether the limits of these be altitudinal or latitudinal" (Gregory, 1954, p. 60).

Problems to be solved in utilising degree days include definition of some total quantity of degree days minimal to plant growth, the dates between which degree days should be accumulated, and the actual process of calculating degree days. Symons suggests wheat requires 1960 degree days (42°F base temperature) and finds evidence for this in the maps of accumulated temperature drawn for the British Isles by Gregory (Symons, 1967, p. 28). Using the same base temperature and for Alberta, Longley assesses the study area as receiving 2000 degree days on average (Longley, 1968, p. 4). In experimental work at Rothamstead designed specifically to obtain the critical threshold value or degree days required for wheat the required total was 1960 based upon temperature of 41°F (Unstead, 1912, p.349). Continuing this work with special reference to Canada, and on the basis of actual field results, Unstead suggested an

Edmonton location required approximately 2200 degree days and that this figure decreased to the north. Inference from Unstead's figures suggests a value of approximately 2100 for the study area (Unstead, 1912, pp. 364-365). This figure, based upon 41°F base, the minimum degree day requirement on a 42°F base can be given as approximately 1950, by subtracting 150 (the number of days in the growing season as defined here) from 2100, with only a negligible error. At the recent Canadian Centennial Wheat Symposium the average day degree requirement (42°F base) for Thatcher wheat was estimated at 1935 throughout most of the Canadian Prairies (Pelton, 1967, p. 217). It is interesting to note that for entirely unexplained reasons Carder, in discussing the agroclimatology of northern Alberta, suggests 1000 degree days as the critical threshold (Carder, 1965b, p. 24).

To calculate the number of degree days Gregory's method will be followed because of its simplicity. Thus 42°F is subtracted from each mean monthly temperature, when that temperature is above 42°F and the result multiplied by the number of days in the month. Using this very simple method no error occurs at all unless the mean monthly <u>minimum</u> falls below 42°F, when the resulting total of degree days tends to be larger than it should be, because for a certain period during the month temperatures are below 42°F. Because the resulting figure is an over - rather than an under - estimation, no compensation is made for this error since if the number of degree days is still marginal for cereal cultivation, the direction of the error only serves to emphasize the marginality. For the period 1959-68 the mean monthly temperatures, mean minimum and mean maximum temperatures are given for the nine stations (Table 2.9). This table

Table 2.9 Mean Temperature Records 1959-68

	April	May	June	July	August	September	October
	Athabasca						
MT	36.5	49.2	56.8	61.9	59.1	49.6	40.5
MX		61.1	68.5	73.9	70.0	60.5	
MN	25.3	37.3	45.1	49.9	48.2	38.7	30.9
	Meanook						
MT	37.1	49.7	56.0	62.3	59.3	51.1	42.3
MX	46.6	60.0	67.5	72.3	68.7	60.0	50.3
MN	27.6	39.4	45.8	52.3	50.3	42.1	34.8
	Rochester						
MT	37.1	48.1	58.0	60.9	57.9	49.6	40.7
MX	48.4	60.7	70.9	74.2	70.2	62.8	52.7
MN	25.7	35.5	45.0	47.7	45.5	36.2	28.6
	Newbrook						
MT	35.4	48.1	56.0	59.7	57.0	48.9	39.6
MX	46.3	61.0	69.5	72.7	69.2	61.1	51.0
MN	24.3	35.2	41.5	46.7	44.7	36.5	28.1
	Lac La Biche						
MT	35.9	48.7	56.6	61.6	59.0	49.2	40.5
MX	47.0	61.0	68.3	73.3	70.1	60.1	50.5
MN	24.8	36.4	44.6	49.9	47.8	38.2	30.4
	Vilna						
MT		47.8	55.7	60.8	58.0	48.7	
MX		60.3	67.5	73.7	70.2	60.9	
MN		35.3	43.8	47.8	45.8	36.5	
	Iron River						
MT	35.7(36.3)	48.9(50.0)	56.7(57.1)	62.3(61.7)	59.4(58.4)	49.5(49.0)	40.4(38.7)
MX	47.0(48.1)	61.3(63.5)	68.4(71.4)	74.0(75.1)	71.2(71.8)	61.0(62.0)	51.0(50.0)
MN	24.3(24.4)	36.5(36.5)	44.9(42.8)	50.5(48.3)	47.5(45.0)	38.0(35.9)	29.7(27.3)
	Cold Lake						
MT	36.6	49.6	58.4	63.2	60.2	50.0	40.6
MX	47.1	61.3	69.5	74.0	70.8	60.7	50.3
MN	26.1	37.8	47.2	50.5	49.5	39.3	30.8
	Elk Point						
MT	35.8(35.8)	49.4(49.2)	57.7(55.3)	62.6(61.5)	59.7(57.7)	49.9(48.4)	39.8(37.6)
MX	46.7(47.6)	61.8(63.1)	69.6(68.6)	74.8(75.3)	71.4(71.3)	61.4(61.2)	50.8(49.3)
MN	24.8(24.0)	36.9(35.2)	45.8(42.0)	50.4(47.7)	47.9(44.1)	38.2(35.6)	28.8(25.9)

Source: Department of Transport, Meteorological Branch, Monthly Records 1959-68.

MT - Mean Temperature; MX - Mean Maximum; MN - Mean Minimum

Figures in brackets are for 1931-60 period; Source: Climatic Normals, Vol. 1, Canada, Department of Transport, Meteorological Branch, 1968.

Table 2.10 Cold Lake Degree Days 1959-68

	May	June	July	August	September	Total
1959	121	465	688	446	198	1918
1960	217	366	716	570	300	2169
1961	319	672	651	713	69	2424
1962	226	522	564	555	294	2161
1963	205	540	738	698	408	2589
1964	295	534	685	487	132	2133
1965	208	471	696	611	0	1986
1966	310	420	617	505	354	2206
1967	214	411	620	657	459	2361
1968	242	483	601	446	240	2012
					Average	2189
					Median	2165
					Standard Deviation	174

Source: Department of Transport, Meteorological Branch, Monthly Records 1959-68.
Calculations based on Gregory's method (1954).

Table 2.11 Lac La Biche Degree Days 1959-68

	May	June	July	August	September	Total
1959	74	387	629	394	162	1646
1960	183	363	657	530	279	2012
1961	304	606	601	660	57	2228
1962	186	453	502	518	258	1917
1963	155	477	660	586	390	2268
1964	285	489	663	474	123	2034
1965	180	387	632	577	0	1776
1966	291	363	577	484	318	2033
1967	198	369	589	611	423	2190
1968	217	429	567	431	195	1839
					Average	1993
					Median	2022
					Standard Deviation	193

Source: Department of Transport, Meteorological Branch, Monthly Records 1959-68.
Calculations based on Gregory's method (1954).

Table 2.12 Athabasca Degree Days 1959-68

	May	June	July	August	September	Total
1959	112	387	648	403	192	1742
1960	164	366	698	530	270	2028
1961	322	630	583	657	99	2291
1962	220	456	515	520(est)	261	1972
1963	161	483	673	608	414	2337
1964	276	480	639	462	75	1932
1965	202	429	657	605	0	1893
1966	307	378	580	481	318	2064
1967	223	408	614	640(est)	435	2320
1968	223	414	549	425(est)	201	1812
					Average	2042
					Median	2000
					Standard Deviation	202

Source: Department of Transport, Meteorological Branch, Monthly Records 1959-68.
Calculations based on Gregory's method (1954).

Table 2.13 Vilna Degree Days 1959-68

	May	June	July	August	September	Total
1959	65	384	601	391	162	1603
1960	158	369	651	508	228	1914
1961	-	-	-	-	-	-
1962	192	495	502	496	252	1937
1963	161	468	645	577	405	2256
1964	270	462	632	455(est)	93	1630
1965	102	378	583	567	0	1630
1966	273	323(est)	539	446	303	1884
1967	171	339	577	589	417	2093
1968	202	387	512	384	183	1668
					Average	1861
					Median	1884
					Standard Deviation	205

Source: Department of Transport, Meteorological Branch, Monthly Records 1959-68.
Calculations based on Gregory's method (1954).

Table 2.14 Elk Point Degree Days 1959-68

	May	June	July	August	September	Total
1959	109	429(est)	648	415	165	1766
1960	174	393	698	533	267	2065
1961	304	642	623	676	63	2308
1962	167	510(est)	527	542	285	2031
1963	183	516	716	605	426	2446
1964	313	510	682	515	141	2161
1965	198	402	669	605	0	1874
1966	338	408	608	502	360	2216
1967	192	371	617	632	465	2277
1968	242	462	589	453	228	1974
					Average	2112
					Median	2113
					Standard Deviation	195

Source: Department of Transport, Meteorological Branch, Monthly Records 1959-68.
Calculations based on Gregory's method (1954).

shows that the mean minimum is slightly below 42°F for May and September and occasionally for June so that the above mentioned error is only small. Degree days have been accumulated for the May to September period for 1959-68 for stations with a complete mean monthly record (Tables 2.10 to 2.14). From these figures the average number of degree days has been derived (Table 2.15). The May to September period has been used because of its relevance to agricultural practices within the study area.

The length of the growing season in northeast Alberta and the associated number of degree days (42°F base) have varied according to different observers (Table 2.16).

Table 2.15 Average Number of Growing Degree Days (42°F base) 1959-68, May 1 - September 30

Station	Degree Days	1931-60
Athabasca	2042	
Meanook	2133	
Rochester	1976	
Newbrook	1830	
Lac La Biche	1993	
Vilna	1861	
Iron River	2049	1908
Cold Lake	2189	
Elk Point	2112	1783

Source: Department of Transport, Meteorological Branch, Monthly Records, 1959-68. Calculations based upon Gregory's method (1954).

Table 2.16 Length of Growing Season and Degree Days

	Length of Growing Season	Degree Days
Carder (1916-60)	April 29-October 15 (170 days)	2000
Longley (1921-50)	May 1 - September 30 (152 days)	2000-2200
Chapman & Brown (1931-60)	April 27-October 6 (162 days)	1750-2000
Boughner (1950-59)	May 1 - October 15 (167 days)	2100
Hayter (1959-68)	May 1 - September 30 (152 days)	1800-2200

Sources: Carder, 1965a; Longley, 1968; Chapman and Brown, 1966; Boughner, 1964.

N.B. Carder's figures are for the Peace River District.

There is considerable agreement that the growing season starts at the end of April or the beginning of May. In the fall, differences of two weeks occur, and possible reasons for this can

only be suggested. Taken over a period of time, the mean monthly temperature in October is below 42°F but not by very much. As a result it may be argued that, on average, a certain percentage of the mean temperatures in October are above 42°F. A study of the daily as opposed to the monthly records reveals this. Similar reasoning may be used to show that some authors prefer late April for the average date of the start of the growing season. It should be noted, though, that minimum temperatures in April and October are normally below 32°F. Differences in the individual author's interpretations may be also a function of the different time periods involved. In any case definition of the growing season ought to bear some relation to agricultural practices. Within the study area sowing never starts before May and if the grain has not ripened before the end of September, it never will. As a result the May 1 to September 30 period has been used here. Of the interpretations noted above from external sources, only Chapman and Brown suggests the study area receives less, on average, than the required amounts of heat which is taken for the study area as 1950.

For the period 1959-68 the mean and the median are similar (Tables 2.10 to 2.14) so that the mean figures of Table 2.15 can be regarded as the heat availability at the 50% level of probability. Standard deviations for this period are very large, indicating a high degree of variability among years in the availability of heat for crop growth (Tables 2.10 to 2.14). At the 50% level of probability Newbrook and Vilna registered less than sufficient heat requirements whilst all the others were above (Table 2.15). A closer examination of the temperature records of each year for those selected stations

where full records are available, reveals that in three years (1959, 1965 and 1968) the number of degree days was below the basic requirement (Tables 2.10 to 2.14). On the basis of accumulated heat units alone, then, there was little chance of the grain completing ripening in three years out of the ten studied. Chapman and Brown find that across the Prairies in general the growing season based upon mean temperatures of 42°F roughly approximates the frost-free season, based upon 32°F (Chapman and Brown, 1966, p. 6). This is certainly not true for areas on the northern margin of cultivation, such as the study area. If some assessment of frost risk is included, heat availability becomes even less sufficient, because neither May nor September are frost-free in most years. In fact, the chances are that both months will contain a large number of frosts.

A meaningful definition of the heat available for crops ought to include a measure of frost risk. Boughner has derived a freeze-free index (F) which indicates the percentage of degree days available during the frost-free season (Boughner, 1964, p. 5).

$$F = \frac{\text{Total Degree Days in Frost-Free Season}}{\text{Total Number of Degree Days in the year}} \times 100$$

This formula has been modified slightly so that the denominator is given by the number of degree days during the growing season rather than in the whole year. The calculation of degree days within the average frost-free period and the values of 'F' give northeast Alberta a markedly marginal appearance (Table 2.17).

With the exception of Elk Point and Cold Lake, frost occurs, at the 50% level of probability at least, before the heat requirements of cereals are fulfilled. The calculation of degree days on the basis

Table 2.17 Degree Days For Average Frost-Free Period 1959-68

	Degree Days	'F' values*
Athabasca	1696	83%
Meanook	1857	87%
Rochester	1255	63%
Newbrook	1071	59%
Lac La Biche	1624	82%
Vilna	1284	69%
Iron River	1710	83%
Cold Lake	1910	87%
Elk Point	1922	82%

*Modified from Boughner 1964.

of monthly average temperatures for the frost-free season on the basis of monthly averages tends to give the most unfavourable impression of the quantity of heat available for plant growth. For example, if the average date of the last spring frost occurs on May 26 then the mean monthly temperature for May minus 42°F is multiplied by 5 to give the total number of degree days for May. However the mean temperature for the end of May is almost certainly higher than that for May as a whole. A similar error results when the average date of the first fall frost occurs in early September. However, in cases where this does happen the error is likely to be slight since the number of days involved is small. As previously noted the minimum temperature in these months is likely to fall below 42°F, with the result that degree days are over-estimated so that the error in the above calculation merely cancels out an existing one. For the period 1959-68 it can be stated that on the average for the study area as a

whole, heat requirements are met during the course of the growing season at least at a 50% level of probability. Irrespective of frost occurrence however, there is a significant number of years when this is not the case. By including even only a crude form of frost risk (i.e. the average values) availability of warmth is well below the desired level.

Photoperiodism

Photoperiodism is the response of plants to the daily civil light period and there can be no doubt that for spring sown-cereals longer photoperiods do shorten the time taken to maturity. Civil light is the period when the centre of the sun is 6° below the horizon in the morning to when it is in this position in the evening. Duration of daylight is two hours less than the duration of civil light in June. However, there is very little evidence from either field or laboratory to determine fully the extent of photoperiodism. In a comparison of two test sites at Beaverlodge (lat. 55° 12') and Madison, Wisconsin, 800 miles to the south, Carder concluded that the longer day length of Beaverlodge virtually compensated for the extra heat of the more southerly location until after heading when the grain starts to ripen, a process which seemed primarily dependent upon temperature (Carder, 1957). With special reference to part of the present study area, Hozack emphasized the importance of temperature after heading.

"Unfortunately once heading has occurred the effect of greater insolation ceases to have a direct effect upon crops, and subsequent development (i.e. ripening) is dependent upon temperature" (Hozack, 1969, p. 32).

A recent paper has found for two varieties of spring barley, under laboratory conditions, that long day lengths of up to 24 hours, in association with temperatures of 75°F, resulted in maturity in 60% of the number of days required if the temperature were at 55°F. Increasing day length was particularly important in quickening growth in the early stages of plant development although yields were below those obtained when day length was increased in the later stages of growth. Long day lengths in the later stages of growth, however, did not affect growth rates in any way but had a beneficial effect on yields (Faris and Guitard, 1969).

Within northeast Alberta photoperiodism even in the early stages of growth is modified by two important considerations. Firstly, the best results, from both the field and laboratory, have been obtained with extremely long photoperiods, up to 24 hours. The longest day (June 21) as defined by the civil light period is merely 19 hours for the study area. Of more importance than this, however, photoperiodism in any stage of growth cannot be isolated from temperature, and increasing day lengths are most beneficial to growth in association with high temperatures. In field experiments across northwest Canada and Alaska designed to elucidate the principal factors in crop growth at high latitudes, the time taken for maturity was decreased at the higher latitudes only when temperatures were also higher (Guitard _et al_., 1965, p. 8). It was deduced that the more rapid growth at Fort Simpson (lat. 61° 12') and Fort Vermilion (lat. 58° 18') than at Beaverlodge (lat. 55° 12') was due both to longer days and higher temperatures in June and July. At Mile 1019 (lat. 60° 45') the time required for maturity was in fact longer

than at Beaverlodge because temperatures were significantly lower. Elsewhere it has been shown that the full benefit of long days accrues in association with high temperatures up to 93°F (Leonard and Martin, 1963, p. 312). Northeast Alberta loses on both counts having neither excessively long days nor relatively high temperatures.

The highest mean monthly temperature for the hottest month (July) is only 63.2°F (Cold Lake) whilst the highest mean maximum in July is only 74.4°F (Cold Lake). Only Newbrook and Meanook do not record mean maxima of 70°F for August (Table 2.9) . With the exception of Cold Lake, August mean temperatures never reach 60°F, and this is the month when rate of growth is primarily a function of temperature. In June when photoperiodism has its greatest effect upon growth, the highest mean temperature is as low as 58.4°F (Cold Lake) and no station records a mean maximum in the 70°F's. The mean summer temperature (June, July and August) for northeast Alberta, 1959-68, is only slightly higher than those summer temperatures suggested by Baker (1925) and Koeppe (1931) for the absolute, potential limit to wheat cultivation (Table 2.18). Baker and Koeppe's limits were 57°F and 58°F respectively (Fig. 1.1). With temperatures only slightly higher than many locations in the far north, including some beyond 60°N, northeast Alberta does not enjoy the advantages of long day lengths. Hozack seems to be quite correct when he says, "to ripen or not to ripen would appear to be the question" (Hozack, 1969, p. 33).

There has been one notable attempt to include the effect of day length with accumulated temperature in an empirical formula, although the author made the mistake of assuming that rates of

Table 2.18 Mean Summer* Temperature 1959-68

	Temperature (^{o}F)
Athabasca	59.3
Meanook	59.2
Rochester	58.9
Newbrook	57.6
Lac La Biche	59.0
Vilna	58.2
Iron River	59.5
Cold Lake	60.6
Elk Point	60.0

*Summer is defined as June, July and August

growth increase as day length increases and mean temperature decreases (Unstead, 1912). The basic premise of this hypothesis was that the more northerly the location, the fewer the degree days required for wheat to mature because of the factor of day length. For example, Unstead, argued that while Edmonton (lat. 53° 30') required 2200 degree days (41°F base), Dunvegan (lat. 55° 56') in the Peace River District required only 1737 degree days. More recently Pelton also noted, "The degree day requirements are inversely proportional to daylength" (Pelton, 1967, p. 217). In conclusion it must be stated on the basis of the limited evidence available that photoperiodism does not compensate to any important degree for the relatively low temperatures of the study area in terms of rate of growth.

Moisture

Moisture is considered here as one factor in the growth of cereal crops and not as an independent cause of yield variations. Adequate moisture in terms of both quantity and distribution is crucial if crops are to mature fast enough to escape frost damage. It is from this viewpoint that moisture during the growing season is assessed. For spring sown crops within Western Canada moisture supplies are particularly beneficial in May, June and July. Whilst moisture is required for ripening, excessive precipitation in August and September can delay harvesting by preventing the grain from drying. Average precipitation during the growing season and April for the 1959-68 period is tabulated for the study area (Table 2.19).

Table 2.19 Average Precipitation April - September, 1959-68
(inches)

	April	May	June	July	August	September
Athabasca	.85	1.52	2.13	2.93	2.79	1.38
Meanook	.74	1.74	3.37	2.67	3.08	1.47
Rochester	.87	1.79	3.87	3.00	3.11	1.09
Newbrook	.65	1.52	2.13	2.93	2.79	1.38
Lac La Biche	.76	1.64	2.65	3.33	3.13	1.48
Vilna	.60	1.75	3.16	3.04	2.59	1.39
Iron River	.67(.75)	1.75(1.41)	2.35(2.75)	3.35(2.28)	2.29(2.23)	1.28(1.43)
Cold Lake	.69	1.30	1.79	2.71	2.43	1.44
Elk Point	.70(.86)	1.77(1.36)	1.93(2.91)	2.50(2.77)	2.83(2.42)	1.56(1.59)

Source: Department of Transport, Meteorological Branch, Monthly Records 1959-68.

Figures in brackets are for the 1931-60 period, Source: Climatic Normals, Vol. 2, Canada, Department of Transport, Meteorological Branch, 1968.

Rainfall is usually well distributed throughout the growing season with June, July and August the wettest months (Table 2.19). In some areas, notably Cold Lake and Elk Point the two most easterly locations, August receives more rainfall than June. Neither of these two stations receives an average of 2" in June whilst May precipitation for Cold Lake is even less than the September total. On the whole the small rainfall totals in April and May facilitate the working and sowing of crops at a time when the soil generally contains its greatest moisture supplies. Precipitation then increases at a time when plant growth is most demanding of moisture. Towards fall rainfall totals then decline providing good 'average' weather conditions for harvesting. Throughout the study period, whilst droughts cannot be said to have occurred, there has been a tremendous variation in precipitation distribution throughout the growing season (Tables 2.20 to 2.28). Dry early springs (May and June) occurred generally in 1967, and for the most part May rainfall was particularly deficient in 1959. Excessive August rainfall occurred throughout most of the study area in 1959 and 1966 whilst abnormally heavy September precipitation fell in 1968, 1964 and 1960. In these years the distribution of rainfall cannot be regarded as optimal for the most rapid harvesting of crops.

Moisture availability for plant growth is, however, not only a function of precipitation during the growing season but is also dependent upon potential evapotranspiration, soil storage capacity, and a crop's ability to tap soil moisture reserves. The moisture storage of the soil varies with the type of soil and what is stored depends upon precipitation minus evapotranspiration of the preceding

Table 2.20 Athabasca Precipitation Totals 1959-68

(inches)

	April	May	June	July	August	September	October
1959	.42	1.69	2.44	1.25	4.02	1.50	1.85
1960	.19	3.16	6.77	3.05	2.60	2.63	1.57
1961	.84	.84	4.87	1.97	1.22	1.16	1.14
1962	1.86	3.08	4.17	4.87	2.78	.78	1.03
1963	.93	1.92	1.12	3.43	3.33	1.35	.47
1964	1.01	2.60	1.05	3.86	3.97	1.84	.67
1965	.69	2.42	3.95	2.41	4.48	1.46	.16
1966	1.11	2.47	1.71	2.92	5.28	.34	.55
1967	.44	.46	1.80	1.30	1.03	.60	.83
1968	1.02	1.45	3.62	2.78	1.54	1.85	.99

Source: Department of Transport, Meteorological Branch, Monthly Records 1959-68.

Table 2.21 Meanook Precipitation Totals 1959-68

(inches)

	April	May	June	July	August	September	October
1959	.20	1.76	4.09	1.10	5.73	1.03	1.49
1960	.26	2.71	4.96	2.91	1.59	2.66	1.43
1961	.95	.91	4.73	2.92	-	-	-
1962	-	-	-	3.40	1.97	.83	-
1963	.75	1.60	.76	-	4.59	.81	-
1964	-	1.94	4.12	3.56	1.81	2.40	.56
1965	.33	3.01	5.46	1.74	3.39	1.14	.04
1966	1.80	2.56	1.30	3.94	5.11	.22	.38
1967	.83	.22	1.86	1.13	.74	.76	.79
1968	.71	.94	3.02	3.33	3.41	3.41	.90

Source: Department of Transport, Meteorological Branch, Monthly Records 1959-68.
(- no record)

Table 2.22 Rochester Precipitation Totals 1959-68

(inches)

	April	May	June	July	August	September	October
1959	.27	1.35	4.83	1.22	3.77	1.37	2.30
1960	.26	3.07	-	4.85	2.03	2.26	1.82
1961	.84	.79	4.06	2.89	.82	.77	1.51
1962	1.8	-	4.31	4.39	3.96	.41	1.13
1963	.79	2.08	-	3.38	1.96	.88	.29
1964	-	1.87	2.27	-	3.02	-	.28
1965	-	2.90	-	2.41	-	1.17	0
1966	1.65	-	-	-	6.22	-	-
1967	.40	.49	-	1.85	-	.51	.82
1968	-	-	-	-	-	-	-

Source: Department of Transport, Meteorological Branch, Monthly Records 1959-68.
(- no record)

Table 2.23 Newbrook Precipitation Totals 1959-68

(inches)

	April	May	June	July	August	September	October
1959	.23	1.16	3.95	.86	4.47	1.05	1.63
1960	.43	-	-	-	1.83	3.00	1.18
1961	.54	1.16	-	-	.28	-	.93
1962	1.52	2.80	-	6.44	3.69	.52	1.20
1963	.44	1.57	1.10	2.25	2.25	.57	.43
1964	.56	1.63	2.07	3.17	3.56	2.72	.48
1965	.40	2.91	3.11	-	3.05	1.10	.02
1966	1.29	1.72	1.07	2.97		.62	.22
1967	.63	.20	1.42	1.67	1.00	.40	-
1968	.44	.68	2.26	3.13	2.89	2.48	1.21

Source: Department of Transport, Meteorological Branch, Monthly Records 1959-68.
(- no record)

Table 2.24 Lac La Biche Precipitation Totals 1959-68

(inches)

	April	May	June	July	August	September	October
1959	.71	1.46	2.33	2.87	6.54	1.26	.79
1960	.48	2.66	3.10	3.26	3.88	2.03	.85
1961	.69	.61	4.03	3.70	.30	1.13	1.28
1962	.77	2.13	5.59	4.97	2.67	1.16	.65
1963	1.00	2.14	1.44	3.90	2.15	.49	.26
1964	1.45	1.19	.61	3.96	2.36	2.91	.45
1965	.36	2.69	4.32	2.22	4.17	1.05	.25
1966	.85	2.23	1.29	2.08	5.47	.42	.33
1967	.90	.01	1.56	6.04	1.37	.47	1.46
1968	.38	1.25	2.18	1.53	2.42	3.86	.36

Source: Department of Transport, Meteorological Branch, Monthly Records 1959-68

Table 2.25 Vilna Precipitation Totals 1959-68

(inches)

	April	May	June	July	August	September	October
1959	.20	.91	3.71	1.37	6.13	1.18	2.20
1960	.17	2.86	-	3.75	2.48	2.76	1.03
1961	.37	1.49	4.33	3.41	.23	.86	1.17
1962	1.51	3.03	5.25	4.62	1.85	.79	.75
1963	.67	1.06	2.24	3.22	1.76	.49	1.04
1964	.81	1.47	-	3.19	1.99	2.37	.50
1965	.25	3.86	3.93	2.56	3.27	1.11	.39
1966	1.41	1.00	-	2.13	-	.26	.21
1967	.62	.15	1.70	2.13	2.12	.07	1.58
1968	-	-	-	3.98	3.54	3.98	-

Source: Department of Transport, Meteorological Branch, Monthly Records 1959-68.
(- no record)

Table 2.26 Iron River Precipitation Totals 1959-68

(inches)

	April	May	June	July	August	September	October
1959	.40	.61	2.76	2.02	4.72	.79	.98
1960	.35	2.55	-	-	-	-	-
1961	-	-	-	3.03	.26	.77	.79
1962	.73	1.51	6.92	3.51	2.53	.95	.87
1963	.56	-	2.40	-	-	.58	.26
1964	1.57	1.25	.42	7.40	2.47	3.33	.21
1965	.32	4.39	-	2.42	-	.97	.09
1966	1.24	1.81	.96	3.36	2.48	.31	.51
1967	.22	.01	1.14	2.48	1.58	.42	1.14
1968	.66	1.88	1.84	3.60	2.00	3.39	.42

Source: Department of Transport, Meteorological Branch, Monthly Records 1959-68.
(- no record)

Table 2.27 Cold Lake Precipitation Totals 1959-68

(inches)

	April	May	June	July	August	September	October
1959	.46	1.0	3.13	3.19	4.84	1.37	1.37
1960	1.37	2.11	4.01	4.60	5.34	2.79	.17
1961	1.32	.45	3.52	3.22	.53	1.10	.51
1962	.78	2.80	6.91	4.49	3.49	1.17	.40
1963	1.00	.67	3.03	1.55	2.80	.90	.12
1964	1.63	1.68	.22	3.74	3.53	3.81	.23
1965	.33	3.81	3.37	1.98	3.43	1.05	.28
1966	.55	1.07	.56	3.39	3.53	.37	.36
1967	.43	.06	1.26	3.19	.78	.34	1.31
1968	.49	1.08	1.85	3.81	2.34	3.53	.62

Source: Department of Transport, Meteorological Branch, Monthly Records 1959-68.

Table 2.26 Elk Point Precipitation Totals 1959-68

(inches)

	April	May	June	July	August	September	October
1959	.49	.76	4.22	1.88	5.64	2.43	2.70
1960	.56	2.76	4.58	5.67	2.92	.81	.37
1961	.89	.47	-	3.12	-	-	.95
1962	.65	2.02	-	4.37	1.53	.90	.52
1963	.24	1.53	-	-	1.01	.43	.33
1964	1.11	1.51	1.03	-	2.80	3.57	.37
1965	.08	5.30	3.24	2.21	3.79	1.38	.17
1966	.99	1.17	.85	1.51	3.96	.52	.13
1967	.50	.08	2.06	3.94	1.52	.36	2.39
1968	1.47	2.11	1.52	2.27	2.28	3.69	.36

Source: Department of Transport, Meteorological Branch, Monthly Records 1959-68.
(- no record)

period. In northeast Alberta evapotranspiration is virtually nil before April. This does not necessarily mean that soil moisture storage is at capacity in April since much of the precipitation may be lost through run-off, and much snow may sublime or melt and evaporate before infiltration can occur. In fact in many years much of the early spring moisture is derived from excessive precipitation in the previous fall. Potential evapotranspiration is, "the amount of water needed for evaporation and transpiration if optimum growth is to be obtained" (Laycock, 1964, p. 5). Precipitation and potential evapotranspiration are the principal variables in the water balance equation as derived by Thornthwaite (Thornthwaite, 1948). The relationship between these two climatic parameters in association with the level of soil moisture gives patterns of water deficit and surplus. One of the difficulties in plotting these patterns, especially

when large soil moisture capacities are involved, is the actual capacities of different soil types.

Laycock, noting this problem and using Thornthwaite's empirical procedures, calculated for June, July and August 1921-50, moisture deficiency patterns for wheat across the Prairies for several different soil moisture capacities (Laycock, 1964, Figs. 11a, 11b, 11c and 11d). For all these soil moisture capacities, ranging from 1/2" to 12", there was an average deficit in northeast Alberta of approximately 4". A similar result was obtained by determining the deficit patterns according to the wheat plant's ability to obtain soil moisture in different months (Laycock, 1964, Fig. 12d). This deficit increases throughout the growing season, although after July "the condition of the crop will have been determined by then and drought then may not mean much" (Laycock, 1964, p. 28). Although moisture availability is less than moisture need the intensity of the deficiency in most years does not constitute 'drought'. Indeed the water deficit in northeast Alberta is amongst the lowest for any area in Alberta.

Moisture deficit is then the 'norm' but the intensity is not great and actual droughts are extremely infrequent, Currie, estimating them at two in 40 years (Hozack, 1969, p. 35). Similarly Chapman and Brown regard the area as ". . . one of fairly adequate moisture . . . it should not be assumed that droughts never occur" (Chapman and Brown, 1966, p. 14). Although spring moisture supplies are not always 'optimal' for crop growth, it is likely that from the viewpoint of the short growing season, abnormally heavy rain in August and September is the greatest problem. In most years total moisture sufficiency is not

generally the problem, but rather its maldistribution throughout the growing season.

Conclusion

Within the study area, the climatic limitation for agriculture is ultimately a matter of frost occurrence. Marginality of heat units and moisture availability would not be so significant if it were not for the stringent limits imposed by the frost-free season. It is interesting to note that for the years with the shortest frost-free seasons, 1968, 1959, 1965 and 1964 (calculated by ranking the length of the frost-free stations for all stations and combining the results), heat units were also below average (markedly so for 1968 and 1959) and that moisture was badly distributed during the growing season. The 1959 and particularly the 1968 seasons demonstrate this clearly. In both years the frost-free season for the region as a whole was short, the August and September rainfall abnormally heavy and the quantity of heat units considerably below the desired level. Frost must be regarded as a risk even in those years when temperature and moisture supply are optimally combined. In those years when one or both of these factors are below average for plant growth, the frost hazard becomes severe. Whilst low evaporation rates do seem to offset the low precipitation amounts, to some extent at least, photoperiodism does not compensate for the relatively low temperatures.

There have been several previous attempts at classifying the climate of the study area for agriculture. It is easier to categorize frost and heat units together because both are a function of temperature and, in that sense, related to one another. Longley

gives the study area 2000 - 2200 degree days and 100 frost-free days (Longley, 1968, pp. 3-4). Chapman and Brown, more pessimistically, associate northeast Alberta with 1750 degree days and 80 frost-free days (Chapman and Brown, 1966). Both suggest the study area as a region of climatic hazard, the former indicating a serious frost hazard and the latter a severe frost hazard, the difference between the two being,

"By serious frost hazard is meant that the wheat is only reduced in quality by one or two grades and with practically no loss in yield. Severe freezing . . . reduces quality to feed grade and cuts down yield" (Chapman and Brown, 1966, p. 9).

At the Canadian Centennial Wheat Symposium Bowser suggested a compromise. "The frost free days average from 75 to 90 and the heat degree days between 1900 and 2150. All crops typical of the region can usually mature but wheat is often damaged by frost" (Bowser, 1967, p. 56). Inclusion of moisture in an agroclimatic classification poses a difficult problem. However A.R.D.A., including frost, heat units and moisture, have classified the study area as "under a severe handicap for agriculture" (Chapman and Brown, 1966, p. 15). Since these authors feel the region is" . . . one of fairly adequate moisture" (p. 14), the agroclimatic classification is therefore primarily based upon the short frost-free season. Similarly Bowser considers moisture only as "a moderate limitation" (Bowser, 1967, p. 56) and also bases his climatic classification of the area on frost, and implicit in this the low amounts of heat units. To summarise,

"The shortness of the growing season and the occasional occurrence of summer frosts place severe restrictions upon agriculture" (Chapman and Brown, 1966, p. 14).

CHAPTER III

SAMPLE AREA ANALYSIS: A MICRO-CLIMATIC ASSESSMENT

Within the study area, although the meteorological stations have recorded considerably different frost-free seasons, various observers have been unable to identify, with any certainty, areal differences in the frost-hazard intensity. Noting that the length of the frost-free season is largely a function of minimum temperatures this has been because, "The variation . . . in minimum temperatures, can be so rapid that no set of climatological stations would provide sufficient data to describe the are adequately" (Longley and Louis-Byne, 1967, p. 1). This was written of a topographically similar area south of Edmonton.

Micro-Climatic Variables

The principal factors affecting the distribution of frost over short distances include relief, water bodies, vegetation, and settlement. Many of the sharpest variations in frost occurrence result from relief (i.e. slope) changes. On calm, clear nights cold air drains downslope to collect in small troughs, depressions in the general surface level, and in the valleys of creeks and small streams, causing temperature inversions. Such 'frost hollows' are frequently 10°F or more colder than adjacent slopes or plateau tops. This inversion effect has a pronounced effect on the length of the frost-free season. For example, the Meanook and Rochester stations (the

latter now disbanded) are both situated on the same general plateau surface to the west of the River Tawatinaw only 19 miles apart. Yet the average frost-free seasons, 1959-68, differ by 51 days. The difference in altitude between the stations is only 125' but Meanook is situated on a knoll rising above the general surface level, and Rochester is at the foot of a very gradual slope. In a minimum temperature study utilising the results from temperature traverses in the Springdale district of central Alberta Longley and Louis-Byne (1967, p. 12) noted temperature inversions of as much as 15°F due to cold air drainage. One of their conclusions was that in many low spots frost should be expected in every month of the year. In 1933 Albright had made similar remarks for certain depressions in the Peace River Country (Albright, 1933, p. 615). Slopes are also important in their compass direction. In a study of climatic variations on a conical hill near Aberystwyth, Wales, Taylor found that the potential growth was 50% greater on south slopes than on north facing slopes (Taylor, 1967, p. 33). This characteristic was again observed by Albright with reference to the Peace (Albright, 1933, p. 615).

The effects of cold air drainage and heat losses caused by nocturnal radiation are modified by the presence of large bodies of water. Water absorbs heat during the day to a far greater depth than the surrounding land so heat loss at night is much slower. Much of the early settlement of the north was on the banks of such large rivers as the Athabasca and Peace, and lake shores. Longley notes that at both the Lac La Biche and Cold Lake stations, proximity to large lakes has caused longer frost-free periods than might otherwise have

been the case (Longley, 1967, p. 248). Excessive sub-surface moisture, however, given topographical expression by swamps and muskegs, results in frost-prone localities. The effects of moisture in this case result in the maintenance of cold, damp conditions. Along the Springdale temperature traverse, for example, there were consistent drops in temperature of 4.1^{o}F in areas of muskeg (Longley and Louis-Byne, 1967, p. 9). Damp swampy or muskeg spots are often found in low areas where they emphasize the inversion caused by cold air drainage. This gives substance to the hypothesis that cultivation, involving land drainage and the clearance of muskeg, tends to lengthen the frost-free season. Cultivation results in a decrease in the highly organic content of the original soils. The effect of such organic soils is to slow conduction of heat from the soil to the atmosphere as well as radiating heat away to space more efficiently than highly mineralised soils (Currie, 1959, pp. 15-16). This explains the frost proneness of both muskeg areas, peat soils and land that has only recently been cleared. A comparison of sandy and highly organic peat soils in southeast Lancashire, England concluded that the average growing season was 10 - 14 days less on the peat soils because of late frosts (Taylor, 1967, p. 35).

Not all vegetation results in a reduction of minimum temperatures. Tall trees and shrubs particularly in association with a well-cultivated garden protect thermometers placed near them against cold air drainage and also form a barrier to radiation heat losses. The temperature recordings of Elk Point, Athabasca and Iron River are all influenced in this way. Temperatures abnormally high for certain latitudes may also result from the urban 'heat island' effect (Longley,

1967, p. 249). This micro-climatic factor is not considered of any importance within the study area for none of the small towns is likely to be sufficiently large to cause such an effect. Although minimum temperatures are broadly a function of latitude, altitude and distance from the sea, the micro-variations within any region may be considerable. An holistic study of the frost hazard must include these effects.

Temperature Traverses

In order to 'measure' the micro-climatic effect upon minimum temperatures in northeast Alberta a series of temperature traverses was conducted in the fall of 1969 using the same methods, instruments, and procedures as in the earlier Springdale study (Longley and Louis-Byne, 1967). Briefly, a sensitive temperature-recording element attached to a thermograph is fixed on the hood of a car which is then driven around a pre-selected route. Variations in temperature are registered on the thermograph. In order to obtain variations in minimum temperature the traverses should be conducted on calm, clear nights between one hour before and half an hour after sunrise when temperatures are both at a minimum and constant. By driving the car at a constant speed and noting (using a tape recorder) topographical features along the route, it is possible to plot the distribution of minimum temperatures and to relate them to topography. In this study the traverses were started at the meteorological station in each sample area and in most cases completed there. This allowed an assessment of the station's frost records in relation to the surrounding sample area and provided a 'fixed' recorded temperature to test the constancy of temperature during the period of the traverse. The

routes selected crossed themselves several times to give another test of constancy. With constant temperatures the results do not have to be adjusted.

One temperature traverse was conducted for each of the nine sample areas, and the question arises as to the reliability of the results obtained. However, "The consistency of temperature patterns on clear nights . . . permits one to use the observations of one morning to show the general pattern of temperatures for the route" (Longley and Louis-Byne, 1967, p. 12). Finally, it should be observed that the temperatures obtained from the traverses are on a Centigrade scale whilst the temperature recorded by the meteorological stations are on a Fahrenheit scale. However, temperatures quoted in the text (and Appendix B) are given on both scales. All the figures drawn on the basis of the results of the temperature traverses contain temperatures only on the Centigrade scale.

Sample Area Analysis

The combined results from the temperature traverses provide an invaluable source of data for a more complete meteorological assessment of the frost hazard in the study area. A detailed analysis (with figures and tables) of the traverse results for each of the sample areas is written up in Appendix B. Only the general procedures and conclusions are included in the main text. However it should be kept in mind that the observations made in the remainder of this chapter are based upon the analysis provided in Appendix B.

The format for the analysis of each of the sample areas is similar and so permits generalisations and facilitates comparisons.

The maps and diagrams drawn for the sample areas are based upon 1:50,000 topographic sheets except for Vilna, Lac La Biche, Newbrook and Elk Point where the map coverage at the largest scale is at 1:250,000. Maps were all surveyed in the early 1950s and most of the information is still relevant now, although there are naturally some discrepancies. The largest topographic change since 1950 has been in the distribution of marsh, the rapid increase in farm size and cultivated acreage being largely made at the expense of marsh. Nevertheless it was deemed desirable to reproduce the spatial extent of marsh as surveyed in 1950 (except for Newbrook) for two reasons. Firstly, it was not possible to discover the present distribution of marsh, and secondly marshy, bushy areas are frost prone and this characteristic is likely to be maintained for a number of years, the actual length of which cannot be determined. None of the topographic sheets indicates the distribution of woodland and as a result this has not been drawn on the maps. However, field observations have been noted where relevant in Appendix B, and on the cross-profiles drawn from the results of the temperature traverses.

Finally, the results of the temperature traverses for each sample area are discussed in relation to the meteorological record of each particular meteorological station. For each station's records, 1959-68, the degree of frost risk is given for certain dates in the spring and fall because it is thought that agricultural practices bear some meaningful relationship to these dates, the validity of which will be discussed in the next chapter. These dates are May 15 and June 1 in the spring, and August 31 and September 10 in the fall. For the interested reader Appendix B should now be consulted as the conclusions

from the sample area analysis follows.

Representativeness of Station's Records

Various frost-free isolines have been drawn for northeast Alberta by different observers. Because differences of a few days can be crucial, it is necessary therefore to evaluate which stations are most representative of the study area, or if this cannot be done, to determine the particular localities for which each station is representative. The meteorological record, 1959-68, suggests three quite distinct average frost-free periods for the study area (Table 2.2). The Cold Lake and Meanook stations indicate at least 115 days frost-free, the Iron River, Lac La Biche, Athabasca and Elk Point stations indicate 100 days frost-free and the Newbrook, Vilna and Rochester stations indicate only 70 frost-free days. These records are, however, derived from point locations, which as a result of micro-climatic factors may or may not be representative of the surrounding area. A short, qualitative statement for each station site, the maximum variation of temperature along the traverse route, and the temperature of each station during the course of the traverse have been tabulated (Table 3.1).

From the traverses it seems that the records of the Cold Lake and Meanook stations are not broadly representative except for one or two small areas. Nowhere else along the traverse route did temperatures exceed or even reach that recorded by the Cold Lake station. Along the route within the Meanook sample area, only one other small location (a knoll) reached a similar temperature to that of the station. While these stations' records may be important to

Table 3.1 Station Site and Temperature Variations During Traverses

	Site	Station Temp.	Highest Temp.	Lowest Temp.	Temperature Variation
Athabasca	small rise, garden	26.2°F	27.0°F	23.8°F	3.2°F
Meanook	prominent knoll	27.5°F	27.5°F	19.4°F	8.1°F
Rochester	near foot of gradual slope	36.3°F	37.6°F	30.7°F	6.9°F
Newbrook	level land	23.0°F	30.5°F	18.5°F	17.5°F
Lac La Biche	knoll, next to lake	23.0°F	24.8°F	16.2°F	8.6°F
Vilna	foot of gradual slope	27.1°F	27.1°F	18.5°F	8.6°F
Iron River	small rise, garden	23.0°F	23.9°F	14.0°F	9.9°F
Cold Lake	Airbase location	22.7°F	22.7°F	13.8°F	8.9°F
Elk Point[1]	garden	23.9°F	25.7°F	20.7°F	5°F

Source: Fieldwork 1969. [1]The Elk Point temperature traverse did not provide reliable information and so these figures are misleading (See Appendix B)

a few individual farmers with holdings in particular localities, they must be ignored in a regional assessment of the frost hazard. There can be no doubt that the Meanook station, situated on a large knoll records abnormally high minimum temperatures due to cold air drainage. Although the actual site of the station at the Cold Lake Air Force Base was not visited, it is thought that proximity to large aircraft hangars and Cold Lake itself results in the very favourable minimum temperatures.

The Iron River, Athabasca and Lac La Biche records also imply a longer frost-free season than is generally likely. Both the Iron River and Athabasca stations are situated on small rises and in well

cultivated gardens. Decreases in temperature by nocturnal radiation are particularly reduced at the Iron River station by proximity to shrubs and tall trees. In the late 1950s this station's site was changed precisely because of an overgrowth of garden shrubs. The Lac La Biche station is situated on a prominent knoll overlooking the lake, and so on both counts records minimum temperatures that are higher than for most of the surrounding area. Minimum temperatures along the Athabasca and Iron River traverse routes were as high or higher than the temperature of the meteorological station in only one locality, whilst along the Lac La Biche traverse route, minimum temperatures were the same or higher in only two areas. It is not possible to assess the Elk Point records so precisely because of the particular circumstances associated with the temperature traverse (see Appendix B). However it does seem that the Elk Point station provides a fair account of the frequency of frost occurrence for its surrounding area.

The Newbrook and Rochester stations represent the frequency of frost for a large part of their sample areas, although in both areas there is higher ground where the risk of frost is considerably less than the records would indicate. The Newbrook station is on very level land with no visual changes in slope in any direction, although there is a ridge of high land 100 ft. higher six miles to the east where temperatures are markedly higher than that recorded by the station. The Rochester station is close to the foot of a very gradual slope on relatively high plateau surface and so almost certainly registers the effect of cold air drainage. If the Newbrook records are influenced by cold air drainage, then such drainage must

operate on a large scale, beyond the scope of this study to determine. The Vilna station is situated on a slight slope although the drop becomes much steeper to the south as the valley of the North Saskatchewan is reached. On the whole the Vilna records seem to represent fairly well the surrounding sample area with the larger part of the minimum temperature distribution along the traverse route being within $2^{o}F$ of the station temperature. Marked inversions are limited to particular localities.

In concluding this section it must be stated that no one particular station represents adequately the frost hazard in northeast Alberta. This is particularly so for the Cold Lake and Meanook records. The records of these two stations indicate the most favourable frost-free periods possible within the study area, and are appropriate only for extremely small localities within northeast Alberta. On the other hand the Vilna, Rochester and Newbrook records should not be considered as giving the absolutely least favourable impression of the frost limitation. In these last three areas there were several localities where the minimum temperature was well below that recorded by the station. There is no doubt that in certain depressions frost occurs every month. It would appear then, that extensive tracts of the study area have only 70 to 105 days frost-free. From the results of the traverses, it is postulated that if a single average frost-free day isoline is drawn for the study area a period of at least no more than 85 days would be most representative for the period 1959-68.

The Frost Hazard: A Climatological Model

The frost hazard is often expressed in terms of percentage risk for a series of dates in the spring and fall based on records stretching over a long period of time. Tables 3.2 and 3.3 provide, for certain probability levels, the risk of frost for Elk Point and Iron River for both the 1931-60 period and the 1959-68 period. No other station within the study area has complete records 1931-60.

Table 3.2 Spring Date of Last Frost for a Given Risk

	1931-60			1959-68		
	10%	50%	90%	10%	50%	90%
Iron River	June 25	June 6	May 18	June 7	May 25	May 14
Elk Point	June 29	June 9	May 21	June 5	May 26	May 18

Source for 1931-60 records: Climatic Normals, Vol. 6, Canada, Department of Transport, Meteorological Branch, 1968.

Table 3.3 Fall Date of First Frost for a Given Risk

	1931-60			1959-68		
	10%	50%	90%	10%	50%	90%
Iron River	August 7	August 31	September 25	August 31	September 7	September 22
Elk Point	August 6	August 29	September 21	August 30	September 8	September 29

Source for 1931-60 records: Climatic Normals, Vol. 6, Canada, Department of Transport, Meteorological Branch, 1968.

At the 90% level of risk the spring and fall dates are very similar but at the 10% and 50% risk levels the long term records suggest a very much shorter frost-free period. The value of such risk tabulations is reduced, however, because of climatic cycles, because of possible

changes in the site of a station, because of the possible growth of vegetation and settlement around a station through time, and particularly because of the spatial variations in minimum temperature.

Analysis of the temperature traverses of this study have substantiated previous results and observations. Cold air drainage has been found to be a significant mechanism in creating temperature inversions, which can be just as large when slopes are almost imperceptible as when slopes are relatively steep. Muskeg results in frost-prone localities whilst extensive bodies of water and the higher relief levels enjoy relatively favourable minimum temperatures. Where large bodies of water are present, nocturnal heat losses are considerably reduced. It is unfortunate that agriculture is restricted along the shores of large lakes, in the valleys of large rivers, and on many of the higher relief levels, particularly those which stand out sharply as ridges or knolls. High ridges are frequently wooded, with sterile soils and a relatively low water table. Large valleys, such as the Saskatchewan and the Athabasca, have extremely steep sides and again are frequently forested. Adjacent to most large lakes marsh distribution is usually extensive.

It is difficult to translate the temperature variations highlighted by the temperature traverses into numbers of frost-free days. However Longley in an analysis of temperature variations through time noted, "When the mean minimum is rising slowly in the spring or falling slowly in the Autumn, a difference of 1°C is reflected by a significant difference in the frost-free period" (Longley, 1967, p. 247). The interest here of course is in spatial differences of minimum temperatures, but whatever the cause the effect is the same.

To provide some 'numbers' to show how small differences in minimum temperatures can create large discrepancies in the frost-free season the records of the Newbrook and Meanook stations can be used (Table 3.4).

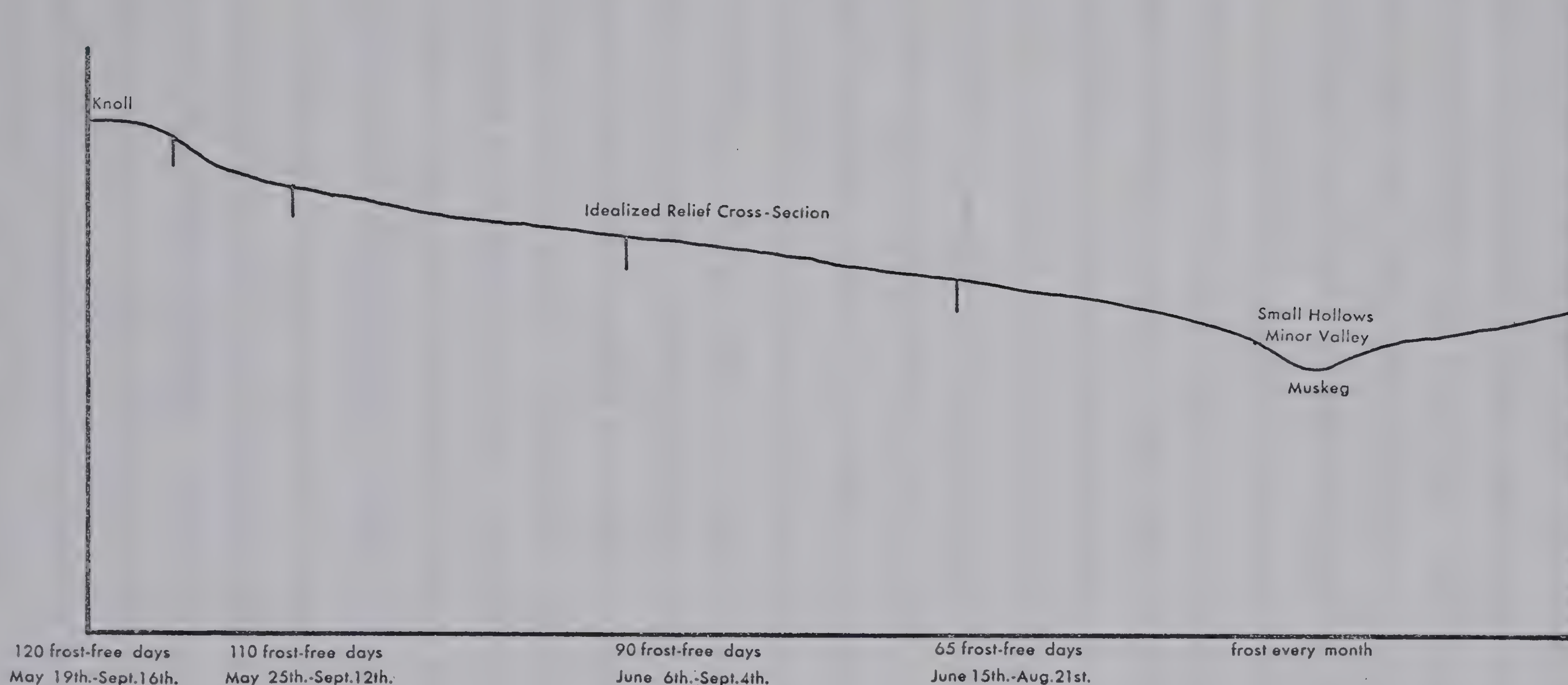
Table 3.4 Average Minimum Temperatures 1959-68 $^{\circ}F$

	May	June	July	August	September
Meanook	39.4	45.8	52.3	50.3	42.1
Newbrook	35.2	41.5	46.7	44.7	36.5

The average variation in mean minimum temperatures is $5^{\circ}F$ but, with these different minimum temperatures, the Newbrook station recorded an average frost-free season 57 days shorter than that recorded by the Meanook station. A difference of only one degree may then be expected to change the frost-free season by one to two weeks. From a detailed examination of the meteorological stations, and from the results of the temperature traverses, a climatological model of the frost hazard for north Alberta has been derived (Fig. 3.1).

Along any particular slope a gradation in frost risk will occur. Going downslope, and assuming no large water bodies are present, the frost hazard increases. As the changes in frost risk are continuous it is not possible to indicate the exact position on the slope when the frost-free period changes by, for example, ten days. However the problem in drawing the boundary should not hide the essential characteristics of the core. The generalisations involved are, in any case, the very essence of a 'model'. From the model it can be concluded that average frost-free seasons of 110 days or more are restricted to

Climatological Model of the Frost Hazard in Northeast Alberta Figure 3.1



the highest hill or plateau tops. Such a frost-free period can also be expected along the shores of large lakes and in large valley bottoms. It must be emphasized that the terms 'high' and 'low' land are used in a relative sense only. Thus 2200' at Newbrook is lowland, and 1875' near Cold Lake is high land. A frost-free period of 90 to 110 days should be expected only on high, well cultivated land or where there is a sufficient body of water. In low lying areas, and shallow hollows an average frost-free period of 90 days cannot be relied upon, and indeed the Rochester, Vilna and Newbrook stations do not even record this amount. Such a frost-free period as recorded by these three stations would also represent those large, steep-sided valleys presently occupied by small streams. None of these stations is in localised frost pockets either. In certain localised depressions and/or in the vicinity of muskeg, frost should be expected in every month of the year. Although gradual and progressive changes in slope, as indicated by the model do frequently occur within the study area, slopes commonly also change rapidly especially on broken terrain and on undulating plateau surfaces. In such cases spatial changes in the frost hazard will likewise be rapid. Barriers to cold air drainage, such as a line of trees, may be expected to provide local 'distortions' to the relationship between slope and the frost-free season.

To the spatial model of the frost hazard it is possible to add a temporal dimension by a yearly analysis, 1959-68 of the meteorological record for selected stations. Although this may not give the long term view it is the actual situation with which farmers are contending. The brief references made to the long term records would suggest that if the longer term view is preferred then for any given

level of risk the frost-free period is shorter (i.e. spring frosts later and fall frosts earlier) than that suggested by the 1959-68 period. To represent areas of different frost hazard intensity the Newbrook (average frost-free period of 67 days), Lac La Biche (average frost-free period of 101 days), and Meanook (average frost-free period of 124 days) have been chosen. If the reader is interested in any other particular station then Appendix B should be consulted. For the current discussion the frost-free and the killing frost-free seasons for each year during the period 1959-68, for Newbrook, Meanook and Lac La Biche have been tabulated (Tables 3.5 to 3.7).

The Meanook records (representing on the climatological model areas with at least 120 frost-free days) certainly give a charitable impression of the frost-free season for such an area (Table 3.5). During the 1959-68 period Meanook has not recorded a frost-free season of less than 106 days (1959), nor a single frost occurrence in June, July or August. On the contrary frost-free seasons of over 140 days have been registered (1960, 1966 and 1967) and the first fall frost has not occurred till October onthree out of the ten years under study. On the basis of the 1959-68 period there is no risk of frost in spring after May 25 or before September 2 in the fall. On May 15 the risk of spring frosts is 50% and this decreases to 10% by May 25. In the fall the probability of frost having occurred on or before September 10 is 50%. As regards killing frosts there is only a 10% risk in spring after May 15, and a 20% risk by September 10 in the fall. The Lac La Biche station is taken to represent the areas with 90 - 110 days on the climatological model (Table 3.6). During the study period very short seasons were recorded in 1968 (60 days), 1965 (72 days) and 1967 (90 days).

It will be noticed that all these years occurred after 1964. Mr. Ed Higham, meteorological inspector for northern Alberta told me that the instrument shelter was much more heavily protected by trees and shrubs until 1964 and he feels this protection was quite significant in reducing heat loss at night (Pers. Comm., Feb. 1970). On May 15 there is a 90% chance of a spring frost and by June 1 the risk is 40%. The probability of killing frosts for the same dates is 40% and 10% respectively. Thus even on relatively high land killing frosts are a possibility in June. In the fall there is a 10% probability of frost before August 31 and a 70% probability by September 10. There is even a risk of a killing frost (10%) in August in such areas. By September 10 there is a 30% chance of a killing frost.

The Newbrook station is representative of low lying level areas and the frost records for 1959-68 show a remarkably short frost-free season (Table 3.7). Only 1961 recorded a frost-free season of more than 100 days. Years with particularly short frost-free seasons were 1966 (23 days), 1959 (45 days) and 1968 (48 days). On the basis of 28°F a killing frost-free period of only 60 days was recorded in 1968, while a 32°F frost occurred in every month except July. Frosts have occurred in July and August in six of the ten years of the study period. The risk of a spring frost after May 15 is 100% and after June 1 the risk is still as high as 60%, which is still the risk level for a date as late as June 22. There is therefore a strong probability of a late June frost in such areas. There is even a 20% risk of a killing frost after June 1, the risk of such a frost on May 15 being 80%. In the fall the risk of frost is 60% and killing frosts 10% before August 31. By September 10 the respective probabilities

are 100% and 60%. A study of the Newbrook, Lac La Biche and Meanook records indicates that July is the month with fewest frosts. However July frosts have been recorded by the Newbrook, Vilna and Rochester and surprisingly, Cold Lake stations so that even in July a farmer in northeast Alberta cannot be certain to miss frosts. This spatial and temporal analysis of frost risk will be the meteorological basis upon which agricultural adjustments to the frost hazard will be assessed in chapter five.

Table 3.5 Meanook Frost-Free and Killing Frost-Free Seasons, 1959-68

	Frost-Free Period (Days) 32°F	28°F	Dates of last Spring and first Fall frost 32°F		28°F	
1959	107	139	May 25	September 9	May 13	September 29
1960	143	157	May 19	October 9	May 5	October 9
1961	120	124	May 13	September 10	May 12	September 10
1962	113	123	May 13	September 3	May 8	September 8
1963	120	163	May 20	September 17	May 20	October 30
1964	119	181	May 14	September 10	Apr. 28	October 26
1965	109	155	May 20	September 6	Apr. 21	September 23
1966	143	165	May 13	October 3	Apr. 30	October 12
1967	145	163	May 11	October 3	May 11	October 21
1968	125	133	May 18	September 20	May 10	September 20
Averages	124	150	May 17	September 18	May 7	October 4

Source: Department of Transport, Meteorological Branch, Monthly Records 1959-68.

Table 3.6 Lac La Biche Frost-Free and Killing Frost-Free Seasons, 1959-68

	Frost-Free Period (Days) 32°F	28°F	Dates of last Spring and first Fall frost 32°F		28°F	
1959	107	139	May 25	September 9	May 13	September 29
1960	124	157	May 25	September 26	May 5	October 9
1961	108	123	May 17	September 2	May 13	September 13
1962	101	123	May 24	September 2	May 8	September 8
1963	116	156	May 27	September 10	May 20	October 23
1964	122	151	May 11	September 10	Apr. 28	September 26
1965	72	108	June 23	September 3	May 21	September 6
1966	109	156	June 7	September 24	Apr. 30	October 3
1967	90	111	June 23	September 21	June 4	September 23
1968	60	90	June 14	August 13	May 15	August 13
Averages	101	131	June 1	September 10	May 13	September 21

Source: Department of Transport, Meteorological Branch, Monthly Records 1959-68.

Table 3.7 Newbrook Frost-Free and Killing Frost-Free Seasons 1959-68

	Frost-Free Period (Days) 32°F	28°F	Dates of last Spring and first Fall frost 32°F		28°F	
1959	45	102	June 28	August 12	May 30	September 9
1960	84	132	June 4	August 27	May 15	September 24
1961	108	109	May 17	September 2	May 17	September 3
1962	94	123	May 31	September 2	May 8	September 8
1963	63	123	June 23	August 25	May 20	September 20
1964	58	102	May 31	July 28	May 31	September 10
1965	72	108	June 23	September 3	May 21	September 6
1966	23	125	June 29	July 22	May 14	September 16
1967	77	111	June 23	September 8	June 4	September 23
1968	48	60	June 22	August 9	June 14	August 13
Averages	67	109	June 14	August 20	May 24	September 10

Source: Department of Transport, Meteorological Branch, Monthly Records 1959-68.

CHAPTER IV

CEREAL CROPS AND FROST DAMAGE

The complicated nature of plant physiology prevents any simple assessment of the frost hazard using meteorological data alone. Crops, and even different varieties of the same crop, vary in their response to frost, whilst the effect of frost differs for the same plant at different stages of growth. The frost risk is necessarily greater temporally, but not necessarily physiologically, for long season crops than for fast maturing crops. There are yet other factors involved in the nature of frost damage, particularly the intensity and duration of the frost, the number of times the plant is frozen and the weather conditions both before and after the frost.

Mechanism of Frost Damage

The actual mechanics by which freezing temperatures and the creation of ice crystals damage or kill plants is not yet fully understood. Frost damage to grain crops is probably the result of both rupturing and dehydration of cells. In its crudest form the rupture hypothesis involved the misconception that expansion occurs as water is solidified into ice (Levitt, 1956, p. 1). However, formation of ice crystals must dislocate the cell structure of plants thus, to a certain extent, validating the notion of rupturing.
Some see frost damage as a result of a dehydration process and therefore comparable to the effects of drought. Simply this theory

states that after a period of undercooling ice crystals form and are enlarged by drawing off the solution contained within the plant cells. Undercooling is necessary because a plant tissue constitutes a solution having a certain osmotic pressure and which will not therefore freeze at the freezing point of pure water (32°F) but at one or two degrees below this (Bouchet, 1965, p. 176). The lower the temperature the more ice is formed in the plant and the greater the dehydration of the cells (Ventskevich, 1936, p. 129). The comparability of drought and frost effects has been observed, frost resistant plants generally also being drought resistant (Waldron, 1932).

Factors Affecting Frost Damage

There are many factors which help determine the extent of frost damage but the single most important one is the susceptibility of plant tissue and the variations in this susceptibility through the growing season. The importance of this factor demands separate attention. Other variables involved in frost injury include the cold hardiness of plants, post-freeze weather conditions, the intensity and duration of the frost, soil moisture, and types of chemicals used on the land. To begin with, it is possible for freezing temperatures to damage plants without the formation of ice crystals. This type of frost, the so-called black frost, depends upon an uncommonly low dew point and damage of this sort is extremely rare (Young, 1941, p. 6).

The degree of cold hardiness, which is especially important for spring sown cereals in the early stages of growth, is largely a function of temperature. The carbohydrate content of a plant gives it a certain degree of protection against frost and these reserves

accumulate when the minimum temperature during the very early life of a plant is between 28°F and 41°F (Pelton, 1967, p. 216). Dantuma and Andrews (1960) found significant increases in the cold hardiness of a number of varieties of winter wheat, spring wheat and barley, when the plants, all in the sprouted seed stage, were exposed to constant temperatures of 34.7°F for periods varying between one and five weeks. Barley and winter wheat varieties also showed increased cold hardiness even after exposure to temperatures of 24.7°F. If, prior to a frost, temperatures have been high cold hardiness decreases and the risk of frost injury becomes much greater. The post-freezing weather conditions can also be critical to a plant's chances of survival. A quick thaw involving rapidly rising temperatures may result in further physiological stress and dehydration of the plant. Slowly rising temperatures and the availability of moisture, on the other hand, will allow the plant to recover satisfactorily.

Levitt feels that the duration of light is a factor in the hardening process because light stimulates the photosynthetic accumulation of carbohydrate reserves (Levitt, 1956, p. 35). Those fertilisers such as potassium and phosphorous that have little visible effect upon foliage but increase root growth also increase the plants uptake of mineral nutrients and rate of photosynthesis which result in a greater degree of cold hardening. However resistance to frost is reduced by the application of nitrogen fertilisers which produce rapid growth in cells rich in water but low in carbohydrate content (Bouchet, 1965, p. 177). From field observations in Alberta in the spring of 1969 several district agriculturalists noted that certain week killing sprays resulted in highly frost prone localities(Alberta, Department of

Agriculture, 1969).

Frost damage also depends upon the rate of the freezing process. Rapid freezing causes more damage than slow freezing but because rates of freezing do not vary by very much under natural conditions, the duration of freezing is more important. For a number of wheat varieties 'significant' differences in the amount of injury resulted when frosts of 4° to 14°F lasted four hours instead of two (McCalla and Newton, 1934). Frost damage may also result from a number of freezings at a temperature which normally would not damage the crop, especially if between freezings the soil thawed out sufficiently to allow the plants to absorb more water (Levitt, 1956, p. 35).

Opinions differ on the relationship between soil moisture conditions and potential frost damage. Klages, in an experiment conducted in 1926 appeared to have resolved much of the misunderstanding (Klages, 1926). His experiment involved the freezing of wheat seedlings in the 2 - 3 leaf stage down to temperatures as low as -5.8°F in a variety of soil moisture conditions, up to a soil moisture content of 50%, and the use of 4 different soil types. Initial damage was greater on the moist soils, but once started, the rate of killing was much greater on the dry soils. Even under the extreme temperatures noted above, there was a much higher survival rate on the higher moisture content soils than on the lower moisture content soils. Klages concluded, "A high soil moisture content is of protective value in the use of rapidly fluctuating temperatures such as occur especially in early spring. Under such conditions it aids in keeping the soil temperature uniform and is instrumental in reducing damage to plants" (Klages, 1926, p. 191).

However, it can be argued that as initial damage is greater on moist soils, the frequency of frost occurrence will be much greater, and unless a considerable degree of freezing is involved, moist soils are likely to be more frost prone. The nature of frost damage to plants then is extremely complicated. Plant susceptibility to frost damage is, however, primarily a function of differences in plant resistance at different stages of growth.

Frost Damage and the Stage of Growth

Freezing temperatures can damage cereal crops in any stage of growth so long as there are sufficient degrees of frost. Crops do, however, vary tremendously in response to frost at different stages of the crop season. It is possible to divide the life of a spring sown crop into five main categories which have relevance to an assessment of the frost hazard.

Tables 4.1 Stages of Growth of Spring Sown Cereals

Stage	Growth Habit
1	2 - 3 leaf
2	Flowering
3	Heading
4	Physiological Maturity
5	Agricultural Maturity

Source: Kondra, Pers. Comm., March 1970.

Stage 1 marks the end of the germinating and sprouting period of the seedling. Stages 2 and 3 occur very close together and the order of occurrence of these stages in fact varies with crops and varieties (Table 4.3). Between Stages 3 and 4 the grain is ripening

whilst the difference between physiological and agricultural maturity is merely one of moisture, the grain being drier at the latter stage, and when agricultural maturity is reached the crop is ready for threshing. One benefit of this stage of growth approach is that although different crops vary in their response to frost, the relative resistance of all temperate cereal crops and their varieties is the same within each of the different stages of growth.

In the case of spring sown cereals, plants during the spring are generally in their most cold hardened condition and are therefore highly resistant to frost injury. During the early life of a cereal crop the plant is suceptible to frost at the 2 - 3 leaf stage but even during this particular stage the crop is more resistant than at anytime during the late developmental periods. The flowering and heading stages are the most susceptible of all to frost injury when an extremely light frost of only 2 or 3 degrees F will cause substantial losses in both yield and grade. Between stages 3 and 4 the grain ripens and the resistance of the plant to frost becomes progressively higher until the grain is ready to be harvested (stage 5). By the time physiological maturity is reached, a frost of 4 degrees F will reduce grade but not yield. Ventskevich, a Russian agro-meteorologist, attempted to express the degrees of frost required to damage various crops in three different stages of growth as indicated in the following table. Fruiting is the reproductive stage immediately after heading. These temperatures, if anything, are on the high size, but they are of the right order of magnitude and indicate that an extremely severe frost is required in the very early stages of growth for any damage to occur. In the flowering and heading stages no

Table 4.2 Stage of Growth and Frost Resistance

	Degree C		
	Spring Germination	Flowering	Fruiting
wheat	-9, -10	-1, -2	-2, -4
oats	-8, -9	-1, -2	-2, -4
barley	-7, -8	-1, -2	-2, -4

Source: Ventskevich, 1936, p. 138.

detailed explanation of the effect of frost is required. A light frost in these stages will not damage the foliage but will severly damage the soft, succulent tissues of the floral parts in the head and thereby considerably reduce, if not eliminate, any economic return. In the other stages of growth opinion is more varied as to the precise effects of frost.

Spring Frosts

In this discussion, spring frosts are defined as all those frosts occuring before flowering. It would seem essential to know in as much detail as possible the effects of spring frosts since over most of the Canadian West, sowing invariably starts before the date of the last spring frost. In northerly areas such as the study area, several frosts are to be expected after the first sowings. There are, however, contradictory beliefs as to the effects of such frosts. "It is believed that a frost at the proper time may induce increased stooling and lead to an apparent thicker stand" (Waldron, 1931, p. 627). Harrington also noted the assumption held by many farmers in the Canadian West that spring frosts do little permanent damage to small grains

except perhaps for a slight delay in the time taken for maturity (Harrington, 1936, p. 374). Conversely Waldron under experimental field conditions found that a spring frost of 6 degrees F reduced the eventual yield of a wheat variety, Hope, by 38% (Waldron, 1932). After a week of consecutive frosts, other varieties more frost resistant than Hope suffered injury which persisted through the life of the plants resulting in decreased yield and height. These spring frosts occurred when the wheat crops were in the 2 - 3 leaf stage. A study of wheat, oats and barley again in the 2 leaf stage, after a June 4 frost of 3 degrees F (screen temperature) at Saskatoon revealed a considerable range of damage including some varieties where all the plant above the ground was killed (Harrington, 1936). Results from an experimental farm in Nebraska indicated that spring sown cereal crops in the 2 - 3 leaf stage are less resistant to frost damage than either seedlings in the previous 1 leaf stage or in the post 4 leaf stage (Peltier and Kiesselbach, 1934, p. 682). In fact, as previously noted frosts in the very earliest stages of growth may increase a plant's cold hardening.

The common belief, noted earlier, that spring frosts are usually of little consequence and occasionally may be of some benefit, results partly from the fact that even when virtually all of the exposed plant has been killed, the plant generally recovers and replaces its ruined parts. After observing the effects of an abnormally severe frost in June, 1969 within the study area, there is no doubt that for the most part visual recovery does take place. It is probable, however, that damage from spring frosts, especially in the 2 leaf stage, has been underestimated, and that apart from the delay in time taken to

maturity (which could be as much as two weeks), injury does result in the form of reduced yields. The farmer, of course, has little means of assessing the effect of a spring frost on his fall yields, for other complicating factors may have intervened by that time. The few studies that have made positive attempts to reveal the effects of spring frosts have generally concluded that the 2 - 3 leaf stage is the most vunerable and that "a crop which is badly frosted in the seedling stage suffers permanent injury" (Harrington, 1936, p. 374). All observers agree that spring frosts delay time to maturity and therefore increase the risk of frost at later stages. Salmon provides a nicely balanced comment which sums up well the uncertainty of the relationship between spring frosts and crop damage.

"Early spring freezes usually are not very destructive to spring seeded small grains, since with the exception of buckwheat and rice, they are not easily killed and usually recover very quickly. Losses do occur, however, and as noted by several observers the damage may be greater than supposed even though the plants are not killed" (Salmon, 1941, p. 328).

Fall Frosts

For the present purposes a fall frost is any frost during or after the flowering stage. The effects of early fall frosts during the flowering, and heading stages have already been noted. Frosts occurring after heading and until the crop is ready for harvesting require more explanation. In a study stimulated by the severely frost damaged crop harvested in Western Canada in 1928, when 60% of the largest grain crop then produced was degraded into commercial grades,

four basic types of fall frost damage were distinguished (Geddes, Mallich and Larmour, 1932). The damaging frosts had commenced in the third week of August and caught the crop in the ripening stage. Firstly a 'bran' frost describes a frost which wrinkles the kernels of the grain. Secondly a 'heavy' frost occurs when kernels are wrinkled and the damage is extended into the crease. Frost also prevented maturity in a considerable amount of the grain sampled and these effects were categorised into thirdly, immature and fourthly, green kernels. All types, except the bran frost, resulted in both yield and grade losses, the bran frost only reducing the grade. The study concluded that the degrading of wheat in 1928 was 'almost entirely' due to frost injury and that apart from discrepancies in Nos. 3 and 4 wheat, the degree of frost damage gave a good indication of flour yield and baking quality.

In an effort to determine the effect of various degrees of frost on a number of wheat varieties at different stages of maturity, wheat samples were obtained from farms around Edmonton from August 5 to September 18, 1929-32 (McCalla and Newton, 1934). The samples were exposed to varying amounts of frost from 4 to 14 degrees F and compared in grade and yield, to a check sample unaffected by frost. The experiment covered all stages of maturity, this being assessed on dry matter content. Even when the samples had become fully ripe for binder harvesting, the authors found no evidence to suggest that grades had become any less sensitive to frost injury. Wrinkling and blistering of the bran were sufficient to degrade wheat seriously.

"Quite mature wheat shared a high percentage of wrinkled or blistered kernels after exposure, and other things being equal, this

percentage largely determined the grade of the wheat" (McCalla and Newton, 1934, p. 417).

When the wheat was not fully mature, exposure to 8 degrees F of frost or more in the artificial freezing chambers reduced grades to Feed or No. 6. Exposure to 10 degrees F of frost or more involved yield losses. Frosts of only 4 degrees F reduced grades but did not affect yield. The amount of damage increased when the freezing processes lasted four hours (the maximum duration of artificial freezing) instead of two hours. The authors also noted that freezing in the field would be greater than that artificially produced because each head of grain would be exposed to maximum radiation on all sides (McCalla and Newton, 1934, p. 416).

In conclusion, after heading, the grain gradually ripens and the moisture content decreases and the grain becomes more frost resistant. However until physiological maturity is reached yield as well as grade losses can result. After physiological maturity the crop is usually swathed and in this case the frost hazard is reduced more rapidly due to more rapid drying than if the crop is left standing.

Crop Type and Frost Resistance

It is common knowledge that different crop types, and different varieties of the same crop vary in their resistance to frost. Detailed knowledge of the varietal resistance to frost is, however, to say the least, vague. Ventskevich found wheat, oats and barley in that order, the most resistant to frost in the spring, whilst in the flowering and late stages of growth he could not determine any

differences between the crops (Table 4.2). Harrington, noting the effects of a June frost, discovered wheat, barley, oats and flax in that order to be the most resistant to frost. The flax varieties particularly were found to be badly damaged (Harrington, 1936). On this point the Alberta Farm Guide similarly emphasizes the highly susceptible nature of flax to spring frosts (Alberta Farm Guide, 1967, p. 48). At Saskatoon differences in frost resistance were observed between varieties. Amongst the wheat for example Reliance and Mindum were outstanding and shared virtually no frost injury. Thatcher came next, followed by Marquis, Garnet, Apex and Pelissier, whilst Reward and Ceres shared the least resistance (Harrington, 1936). Only Garnet and Thatcher of these varieties are grown presently to any great extent within the study area.

Whether a variety is resistant to frost or not can frequently be determined by a study of its ancestry. Marquis, for example, on its introduction to Western Canada was more frost prone than the principal variety it displaced, Red Fife, because one of its parents was Hard Red Calcutta, an Indian strain. Varieties developed from warmer climates tend to have a lower degree of frost resistance than those from colder climates (Waldron, 1931). In McCalla and Newton's study of fall frosts, Garnet was the most resistant wheat variety and Marquis the least resistant, thus emphasizing Waldron's comments (McCalla and Newton, 1934, p. 417). Contemporary evidence on the varietal resistance of crop types and their varieties to frost is, however, scanty.

What evidence there is suggests that in the early stages of growth wheat is the strongest and barley the weakest. If oilseed

crops are included rape would rank the same as barley and flax would rank the weakest. According to Ventskevich at least, oats are slightly more able to resist a spring frost than barley (Table 4.2). In the early seed development stages all cereal crops are probably equally susceptible. Barley and oats are slightly more resistant than wheat in the flowering stage because their heads are protected by a sheath. In the fall oats are probably as resistant as wheat if not more so due to a tougher grain kernel. From a practical viewpoint however the difference in frost damage between crops results more from differences in the stage of growth which results from variations in sowing times and growth rates, than from any inherent characteristics of the crops themselves to frost resistance.

Stage of Growth and Frost Risk

It is now possible to relate the meteorological probability of frost in both the time and spatial dimensions, as indicated by the climatological model of the previous chapter, with the variation in frost susceptibility during the life of the relevant crops. To do this it is necessary to define the average duration and time of occurrence of the various stages of growth for the most widely grown crops within the study area. Also it is necessary to obtain meaningful sowing dates of the various crops characteristic of northeast Alberta. Wheat, barley and oats are easily the most extensively grown cash crops whilst rape is increasing in importance throughout northeast Alberta and flax is significant in certain small localities. Of these crop types, Thatcher and Park wheat, Conquest barley, Victory oats, Echo rape and Raja flax are the most popular varieties. Partially

anticipating the next chapter, a representative sowing date for wheat and flax is May 15, for oats is May 25 and for rape and barley is June 1.

If seeded on fallow land, Thatcher wheat and Raja flax should mature in 120 days, Victory oats in 108 days and Conquest barley in 100 days (Alberta Farm Guide, 1967, pp. 64-69). Results from crops grown on summer fallow land at the University farm, Edmonton, suggest maturity periods of 106 days for Park wheat and 100 days for Echo. For each of these crop varieties the average number of days from sowing and the average dates for the onset of each stage of growth have been given (Table 4.3). These figures are based on the results obtained at the University farm, Edmonton (Kondra, Pers. Comm., March 1970). It should be emphasized that these dates and numbers are strictly averages and that there are likely to be variations due to variable growing conditions of at least two weeks. Furthermore the actual sowing dates upon which the figures are based are again averages thus providing another source of variability.

Ommitted from the figures of Table 4.3 are the durations of the different stages of growth. Wheat is generally in the 2 leaf stage for approximately 4-5 days. The length of time taken for flowering varies from 1 - 3 days for the cereal crops to 10-14 days for flax and rape. The period after flowering when seed development occurs and when the grain begins to ripen, is the longest of all, not being fully complete until physiological maturity occurs. As regards wheat, heading starts before flowering, but in the case of oats and barley flowering starts before heading. However, seed development, which begins with flowering, is not completed until physiological maturity. Physiological maturity is generally 10 days before agricultural

Table 4.3 Stage of Growth for Selected Crop Varieties

	Stage	Thatcher Wheat	Park Wheat	Conquest Barley	Victory Oats	Echo Rape	Raja Flax
		Average Number of Days From Sowing					
1.	2 leaf	15	15	14	14	14	14
2.	Flowering	60	55	43	40	40	40
3.	Heading	56	53	45	42	-	-
4.	Physiological Maturity	110	96	90	100	85	110
5.	Agricultural Maturity	120	106	100	110	100	120
		Average Dates of Days From Sowing					
1.	2 leaf	May 30	May 30	June 15	June 8	June 15	May 30
2.	Flowering	July 14	July 9	July 13	July 7	July 10	June 24
3.	Heading	July 10	July 7	July 15	July 9	-	-
4.	Physiological Maturity	September 2	August 19	August 29	September 2	August 24	September 2
5.	Agricultural Maturity	September 12	August 29	September 8	September 12	September 8	September 12

Source: Kondra, Pers. Comm., March 1970.

maturity.

In assessing the chances of frost damage for these stages of growth, the spatial variation in frost risk must also be kept in mind. The risk of frost for the flowering stage, however, is least for all areas because this stage occurs, with the possible exception of flax, at a time which is generally free of frost, and in any case flowering is of extremely short duration. All the cereals tend to flower in the first week or two of July and in this period only two frosts were recorded in the study area during 1959-68. These were recorded at the Cold Lake and Vilna station, both on July 1, 1968 illustrating that even for favourable localities (Cold Lake) frost is still a risk in the hottest month in the year. On the whole the possibility of frost damage during the flowering stage is extremely small with a less than 3% risk based on data for the 1959-68 period. For flax particularly and for rape, flowering tends to occur earlier and last longer than for cereals, and so the last week in June has to be considered as regards frost risk. In low lying or shallow areas the chances are that frost will occur in late June at least once in two years. However, because rape is generally seeded late, frost risk in the flowering stage is the same for rape as for cereals.

Of all the stages of growth considered here, if frost risk is least at the flowering stage, it is greatest at the 2 leaf stage. After May 15, the usual date of wheat and flax seeding, there is still a more than 50% risk of frost in all areas including lake shores and the highest knolls. Frost is still a considerable risk by the end of May, and in low lying areas the last frost is just as probable after June 14 as before. Given the high frequency of frost in late May in all

areas and in June for low areas, throughout the study area the chances are that some of the crop will be caught in the 2 leaf stage in virtually every year. It is fortunate the crops are generally cold hardened at this stage, and that usually only a delay in maturity is involved.

The very long period after heading is highly vulnerable to frost damage and although cereals become less prone the nearer to the time of physiological maturity, the actual risk of frost occurrence becomes greater. Both now and in the past this period after heading has been the most significant time for crop losses due to frost. This stage lasts on average until at least August 19 for barley, and for some varieties of wheat may not be completed till the beginning of September, by which time frost risk for all areas is approaching 50%. The chances of a September free of frost in any locality is negligible. In fact for low lying areas frost will have most likely occurred in August (greater than 50% probability) and in the rest of the study area, apart from a few favoured localities, frost should be expected in one year out of two before at the very latest September 10. If for any reason physiological maturity is delayed the risk of frost damage is extremely severe. Also if for some reason the farmer does not swath his crops when physiological maturity is reached, he increases the chance of frost reducing the quality of his crop. The reason the grain is swathed after physiological maturity is that the drying of the grain is usually more rapid after swathing than if the grain is left uncut. Assuming that early July is generally frost free it may be concluded.

"Agriculturally the greatest limitation is the risk of frost during the growing season. Specially vulnerable periods for small grains are late May and early June when the grain is sprouting and August

when the heads are filling" (Hozack, 1969, p. 21).

Frost Damage in Northeast Alberta

It is impossible to determine the crop damage caused by frost for any period in the past for Alberta or for any political division within Alberta for the simple reason that such records do not exist. Figures of total yield are available but these mask the real variations caused by the vagaries of weather because grades are never mentioned, and in bad years more than normal amounts of planted acreage are abandoned and yields are calculated on the basis of harvested acreage (Hozack, 1969, p. 18). Furthermore no explanation as to the specific causes of yield variation is given. The Board of Grain Commissioners merely record sampled average values, in terms of grade (only as low as No. 3) and protein content for carlot shipments from each crop district in each province for hard red spring wheat, amber durum wheat and barley (Dempster, Pers. Comm., February 1970). Even the Alberta Hail Insurance Board now extended to cover all farms of crop damage will only partially help rectify this deficiency in the historical record. The scheme is voluntary and is still not available to many areas, including large parts of the study area. Also the reasons for damage claims are not collected and filed by the central office and the maintenance of the more detailed aspects of the insurance records will depend upon the personal whims of the insurance agents.

Estimates and descriptions of frost damage have therefore to depend upon fieldwork. During the fieldwork undertaken for this thesis, farmers' estimates of the fall frost damage of 1968 and opinions on the effects of the spring frosts of 1969 were obtained.

1968 was a year of extensive frost damage, as indeed the meteorological record would indicate. All the stations expect two recorded frosts within the first two weeks of August. As if to emphasize the unpredictability of frost, the following spring registered one of the most severe June frosts on record. The frosts of 1968 and 1969 can therefore be regarded as exceptionally severe.

Frost Damage 1968

Lower than average rainfall in May, June and July 1968, delayed crop development significantly, and in the early part of August much of the grain in northeast Alberta was still in the early part of the heading stage. Grain heads were therefore soft, very moist and extremely frost sensitive. Unfortunately early frosts started between August 9 and 13 across much of northern Alberta, even affecting central areas of the province. Only Cold Lake and Meanook failed to record a frost in August, which illustrates again the lack of representativeness of the minimum temperature records of these two stations for their local areas. In both areas, the farmers sampled reported extensive frost damage. The August frosts caught the crop in an extremely critical stage and much of the grain was killed outright. The rest of the crop was reduced in bushel weight, yield and grade. Harvesting was started when the grain was still green but abnormally heavy September rains delayed harvesting even further with the result that some of the grain was still in the field in the following spring.

Frost damage was reflected in loss of yield per acre, reduction in weight per bushel, and lowering of grade.

Table 4.4 Estimated Yield Losses due to Frost 1968

	Acres		Yield (bushels)	
	Sown	Harvested	Expected	Actual
wheat	6856	5988	220,571	92,387
oats	4605	4057	294,800	175,625
barley	5824	5458	357,800	157,471

Source: Fieldwork, 1969.

These figures were derived from estimates of about 90% of the sample, irrespective of whether frost damage occurred or not, and although they should be regarded as rough approximations, they are of the right order of magnitude. Wheat and barley yields were cut down by more than half whilst oats were reduced by nearly one-third. The relative losses to rape and flax were approximately the same but in total much smaller. Crop losses due to frost were more severe than these figures suggest. Not one single farmer of the population sampled obtained a wheat grade higher than No. 4 whilst Nos. 5, 6 and Feed were by far the commonest. Much of the grain actually harvested could not be sold and had to be fed to livestock. Farmers without livestock were the hardest hit of all. Several farmers reported that grain could not even be fed to livestock.

The August frosts caused the farmer to incur another important cost namely that resulting from a loss in germination which affected virtually all the grain harvested, irrespective of whether yield, grade or weight per bushel was reduced. In this respect, oats, which in many cases in terms of yields was less damaged than the other cereals, was just as badly affected. Farmers were not therefore able to use

their own grain for seed the following year and an abnormally high proportion of the grain sown in 1969 was freshly bought seed as a result of the loss in germination. A total inventory of damage caused by such frosts should include the 'indirect' costs involved. For example, outlays on fertilisers, weed sprays and machinery is money completely wasted when there is crop failure, and can only be paid for by drawing on cash reserves or going further into debt. Fertilisers are particularly expensive and for northern Alberta where the average application is approximately 100 lbs per acre, the cost would be $4.50 an acre or $450 for 100 acres. One farmer in 1968 spent $2000 in fertilising a part of his 620 cultivated acres. In 1969 he still had in storage 25,000 bushels of poor quality grain on his farm with very little hope of any sales. Of the 59 farmers who used fertiliser in 1968, 21 stated that they did not use fertiliser in 1969 either because they doubted its value or more particularly because they could not afford to do so after the losses incurred in 1968.

The 1968 crop losses illustrate the effect of fall frosts in their severest form. It is perhaps worth noting that only three of the meteorological stations (of the eight operating then) recorded a temperature of 28°F or below in August. Cold Lake and Meanook did not even record a 32°F frost. Freezing temperatures were not therefore extreme. The severity of the damage can be explained by the fact that crops were in a frost sensitive stage of growth and because the actual degrees of frost at plant height was much greater than those recorded by the instrument shelter. Some of the stations did, in fact, record a series of frosts in August, notably Vilna (seven frosts) and Newbrook (six frosts), these stations undoubtedly being the most

representative of the occurrence of frost in the fall of 1968. This description of the fall frost damage in 1968 also exemplifies the possible extent of the frost hazard to northern fringe areas, and provides extra evidence that a screen temperature of 32°F is the most critical threshold for determining the length of the frost-free season.

Spring Frost 1969

One of the characteristics of frost is its apparent random and unpredictable occurrence throughout the years. A damaging frost one year does not lessen the chance of such a frost the following year. In the Peace River District crops were abnormally damaged by frost for five consecutive years between 1947 and 1952 (Stacey, 1952, pp. 5-7). With reference to the study area the early fall frosts of 1968 were followed in 1969 by late spring frosts of considerable intensity.

Table 4.5 Temperatures, June 10 - 14, 1969

Station	June 10	June 11	June 12	June 13	June 14
Elk Point	30°F	35°F	26°F	29°F	34°F
Newbrook	30	37	24	26	30
Athabasca II	35	37	30	33	38
Lac La Biche	32	35	26	29	34
Meanook	42	37	29	38	47
Cold Lake	33	34	29	32	36
Iron River	31	34	29	30	34

Source: Department of Transport, Meteorological Branch, Monthly Records, June 1969.

With regards to its spatial extent these frosts affected virtually every part of Alberta. The visual effect of these frosts

was certainly immediate and indicate that once again the screen temperatures severely underestimated frost intensity at ground and plant level. Whole fields of crops were flattened to the ground, as if a roller had passed over them, and the normally green leaves had turned a pale yellow. One farmer in the Cold Lake area showed me a field of alfalfa which was visibly wilting and turning yellow. Even the leaves of spruce trees were killed. The frosts were particularly damaging since they caught most of the later sown crop, especially barley, and rape in the 2 leaf stage. Crops in earlier or later stages seem to have been slightly less affected. Such was the concern as to the effects of these frosts, that the Provincial Government sent out a small questionnaire to all the district agriculturalists of Alberta[1] (Appendix C).

All the district agriculturalists had great difficulty estimating the extent of the damage, only one feeling confident enough to estimate permanent damage for his entire area (Peace River). He surmised that 5 - 10% of all the crops in some areas and barley and rape in all areas were permanently damaged. It was estimated for most parts of Alberta that the frosts would delay most of the crops by one to two weeks and that the dry conditions after the frost had emphasized the delay in crop growth. However, within three weeks most cereal crops were observed to be back to normal except in so far as they were late in developing. Over northern and central Alberta, including the study area, the hay yield was down in most cases, by at least half, although there was much conjecture as to whether this was the result of the dry conditions or the frosts. This may partly result from a

[1]The Provincial Government kindly allowed me to use the questionnaire returns. They were however of little use for detailed analysis, being really a collection of non-standardised observations.

misunderstanding of the mechanics of frost action, which through the dehydration process creates a water need which was not previously there.

The main damage resulting from the June frosts seems to have been in a small reduction in yield, especially in the barley and rape crop and a marked delay in the season for all cereal crops. Although no data were collected and there is no information available on record, personal observations when conducting the temperature traverses suggest that extensive harvesting operations were still being undertaken in late September and early October. Fall frosts began in August within the study area and continued with increasing severity throughout September so there can be little doubt that the cereal crop was eventually reduced in grade, if not in yield.

Conclusion

The frost hazard for spring sown crops has now been defined on physical and bio-physical criteria. From the viewpoint of the frost hazard several suggestions can be made as to the most viable practices for the area. The following proposals ignore for the moment current agricultural practices and present market forces.

1. Except for a few favoured localities, long maturing crops such as Thatcher wheat and flax are not feasible for this area. These crops have to be sown so early that spring frosts are assured in all areas. This fact alone should rule out the possibility of growing flax extensively. Although spring frosts may or may not damage Thatcher wheat, delays will frequently occur and there is only a 50 - 50 chance of harvesting such wheat free of frost on the higher

land, assuming delays in growing do not occur. The successful cultivation of long season crops is further hampered by the marginal nature of other physical factors, especially temperature and rainfall which will tend to extend the time taken for maturity.

2. The severity of the winter and spring eliminates the possibility of growing fall sown crops such as winter wheat and fall rye. Indeed in the south of the Province spring damage is a problem to fall sown crops. Even alfalfa, a legume perennial, is affected by the severe winters. Many farmers have observed in fields of grass-legume mixtures, for example, brome and alfalfa, that more nutritious alfalfa is being progressively reduced through the years by winterkill.

3. Any crops requiring 90 days or more, including early varieties of wheat, barley, oats and rape should only be seeded on the higher land where the possibility of a frost-free season of 100 days is at least 50%. Even this is a high risk level and since even fast maturing wheat varieties (e.g., Park) take almost 100 days to reach physiological maturity, serious consideration should be given to the elimination of wheat, or perhaps more practically, any wheat grown should be given a low priority as an income earner by the individual farmer.

4. The most successful cash crops will be those requiring approximately 90 days or less to reach physiological maturity, notably barley and rape, and perhaps also oats which appears

to be more resistant in the fall. For these faster maturing varieties, seeding ought to be delayed until the end of May and the beginning of June and then grown on the higher land.

5. On the lower levels only the very fastest maturing varieties of barley, grain for feed, hay and pasture are viable crops.

6. Throughout northeast Alberta, frost is a hazard in every month of the year, with the risk being very much greater for low lying areas. Even in July and early August frosts are a possibility in all areas, as the account of the 1968 crop damage has indicated. In terms of this sporadic occurrence of mid-summer frosts and because of limitations posed by frost at the beginning and end of the crop season, farmers in any area should not base their future on cereal crops alone.

7. From the standpoint of the frost hazard, defined in all its complexities, the area is best suited to a livestock and feed grain economy. The return from such practices would be more assured and constant. Also cereals would probably always have a local 'farm market', as feed for livestock. Even for a livestock based economy the low annual minimum temperatures and short growing season pose an extra burden to the region. The winter months last longer in these latitudes than in the areas to the south with a similar 'continental' situation so that there is an extra cost of keeping cattle indoors. Also more feed has to be grown and

stored away in the limited growing season than otherwise would be the case. The growing and baling of large quantities of hay poses a labour problem. Nevertheless a livestock based economy is the one best suited to the frost hazard of the area. In these areas wheat should not be 'king'.

"There are areas where the farmer takes a considerable risk in the production of wheat. Most notable is the northern Prairie with its frost hazard . . . . The farmer must carefully consider the degree of risk he is willing to accept. Major reductions in the frost hazard in these northern areas, and the possible northward extension of our wheat producing area, must come from the development of earlier maturing varieties rather than from our increasing knowledge of climate" (Pelton, 1967, p. 221).

The detailed analysis of the frost hazard within northeast Alberta clearly indicates the climatic limits imposed upon plant breeder and farmer alike.

CHAPTER V

AGRICULTURAL PRACTICES AND THE FROST HAZARD

It is impossible to define a natural hazard in physical terms alone since a hazard is so-defined because existing human practices are insufficient to prevent losses. Any natural hazard is a joint product of physical controls and human adjustment (Russell, 1969, p. 7). Assessment of the frost hazard must finally depend upon the nature of existing agricultural practices and the practical range of hazard reducing techniques. The extent and importance of the frost hazard is therefore ultimately a function of decisions made by farmers.

Structure and Type of Agricultural Economy

To use a single term the agricultural economy of the area can be best described as being one of 'mixed' farming. Of the farms sampled 23% can be classified as mixed, 29% as predominantly cash grain farms and 48% as predominantly livestock farms. This classification is arbitrary and not based upon income receipts but upon the ratio of land under cereals and summer fallow, to that under tame pasture and grasses. Even so these percentages are roughly comparable with the figures provided in the 1966 census for commercial farms for Census Divisions (C D.'s) 12 and 13, which are based upon economic criteria (Table 5.1). This table would suggest that the classification of the Questionnaire farms has over-estimated mixed farms and under-estimated livestock farms.

Table 5.1 Percentage Farming Types

	Census 1961* C.D. 12 and C.D. 13	Questionnaire Returns 1968 C.D. 12 and C.D. 13
Grain	24.5	29
Mixed	13.4	23
Livestock	62.1	48

Source: Census, Agriculture Alberta, 1966, Table 16 and Fieldwork 1969.
*Commercial farms only.

The percentage of cultivated acreage and average size per farm of selected crops in the sampled population and the 1966 Census are also comparable (Tables 5.2 and 5.3).

Table 5.2 Percentage Land Use For Selected Crops

	Census 1966*		Questionnaire Returns 1968	
	C.D. 12	C.D. 13	C.D. 12	C.D. 13
Wheat	25	14	26	13
Barley	13	19	13	22
Summer fallow	16	15	17	16

Source: Census, Agriculture Alberta, 1966, Table 17 and Fieldwork 1969.
*Commercial farms only.

Table 5.3 Average Acreage of Selected Crops Per Farm

	Census 1966		Questionnaire Returns 1968	
	C.D. 12	C.D. 13	C.D. 12	C.D. 13
Wheat	74	60	99	52
Barley	55	86	51	74
Summer fallow	76	67	60	60

Source: Census, Agriculture Alberta, 1966, Table 17 and Fieldwork 1969.
*Commercial farms only.

On the other hand the average size per farm and average cultivated acreage is greater for the sampled population than for those given by the census (Table 5.4).

Table 5.4 Average Farm Size and Cultivated Acreage

	Census 1966*		Questionnaire Returns 1968	
	C.D. 12	C.D. 13	C.D. 12	C.D. 13
Average farm size	602	512	775	850
Average cultivated acreage	341	338	388	428

Source: Census, Agriculture Alberta, 1966, Table 13 and Fieldwork 1969.
*Commercial farms only.

Reasons for the larger sizes of the sampled population result from the nature of the sampling technique and the general annual increase in both farm size and cultivated acreage and because sampled farm sizes included rented and leased land. For example between 1961 and 1966 average census farm size increased by 81.0 acres for C.D. 12 and by 46.1 acres for C.D. 13. One typical facet of the agricultural structure of the area, the low percentage (approximately 50%) of the farm area that is actually cultivated, is well illustrated by the sampled population (Table 5.5).

Table 5.5 Percentage of Farmland under Cultivation

	Census 1966*		Questionnaire Returns 1968	
	C.D. 12	C.D. 13	C.D. 12	C.D. 13
% Cultivated	56.6	66.0	50.0	50.3

Source: Census, Agriculture Alberta, 1966, Table 13 and Fieldwork 1969.
*Commercial farms only.

Another regional characteristic of the farming economy is the high percentage of farmers who have supplementary off-farm employment (Table 5.6).

Table 5.6 Percentage of Farmers with Off-farm Employment (Questionnaire Returns)

None	Full-time	Part-time
57.6	24.2	18.2

Source: Fieldwork 1969.

Off-farm work is obtained as far as possible locally, for example in stores. Within the Cold Lake area most of the non-agricultural income of the farmers interviewed is obtained at the Air Base. Frequently, however, there is insufficient local employment and many farmers sow their crop, leave for the oil fields of the north, and return for the harvest. Off-farm employment would almost certainly be sought on a larger scale if it were not for the relatively old ages of most farm operators (Table 5.7).

Table 5.7 Census Farms Classified by Age of Operator % Frequency

Age Groups	Census 1966 C.D. 12	Census 1966 C.D. 13	Questionnaire Returns 1968 C.D. 12	Questionnaire Returns 1968 C.D 13
- 24	3.0	2.5	1.8	-
25 - 34	16.8	15.8	18.1	16
35 - 44	26.1	25.7	25.5	20
45 - 54	27.4	25.7	40.0	23
55 - 64	19.9	21.3	7.3	25
65+	6.8	9.0	7.3	16

Source: Census, Agriculture Alberta, 1966, Table 14 and Fieldwork 1969.

Over half of the sampled farm operators are at least 45 years old. Excluding the Indian Reservations, the broad features of the agricultural economy of the study area are reflected by the sample.

In more detail the percentage cropland use (Table 5.8) and the average numbers of livestock (Table 5.9) for each of the nine sample areas is tabulated. The figures of Table 5.8 do not indicate the amount of land in mixed grains, and fail to distinguish between oats grown as a cereal grain and oats cut for hay. However, the latter amount is very small; according to the 1961 census oats cut for hay in C.D. 12, excluding the Indian Reservations,was approximately 2% of the total cropland use (Schultz, 1966, p. 43). In terms of use of cultivated acreage excluding summer fallow, grains occupy over 50% of the cultivated acreage, whilst tame pasture and grasses generally occupy over 20%. Newbrook is the major exception, this being the only area where tame pasture and grasses are seeded on a larger acreage than all grains and summer fallow put together. As regards crop cultivation there is one major difference between census divisions 12 and 13 as revealed by both the sample and the census. With the exception of Cold Lake, barley is grown more extensively than wheat in C.D. 13 whilst the opposite is true for C.D. 12. Cold Lake is also notable in the relatively large percentage of rape sown. Vilna and Elk Point, the two most southerly areas, and both within a more fertile soil belt, devote a greater acreage to cereal grains than any of the other areas. A discrepancy also appears between the census divisions in the relative emphasis on pasture and grasses, and also livestock totals, with areas in C.D. 12, excepting Lac La Biche, containing less land of this variety and fewer livestock.

Table 5.8 % Cropland Use in the Sample Areas 1968
(Questionnaire Returns)

Area	Total Cropland (acres)	Summer fallow	Wheat	Barley	Oats	Cultivated Pasture	Tame hay and grasses
Athabasca	8020	19	19	27	10	12	13
Meanook	3630	19	9	24	13	10	19
Rochester	3310	13	15	27	11	15	19
Newbrook	3870	14	9	9	12	28	23
Lac La Biche	4440	9	28	13	13	15	16
Vilna	4910	15	30	13	20	3	15
Cold Lake	4680	21	13	23	12	5	12
Iron River	3660	18	33	9	17	1	14
Elk Point	3640	24	27	7	23	12	8

Source: Fieldwork 1969.

Table 5.9 Number of Livestock
(Questionnaire Returns)

Area	Beef Cattle	Milk Cattle	Pigs	Cattle Per Farm	Pigs Per Farm
Athabasca	726	81	789	73	72
Meanook	337	41	160	34	15
Rochester	763	64	546	75	49
Newbrook	483	40	347	48	32
Lac La Biche	935	13	578	86	53
Vilna	288	56	402	31	37
Cold Lake	356	35	810	36	74
Iron River	446	21	210	42	18
Elk Point	308	47	466	32	42

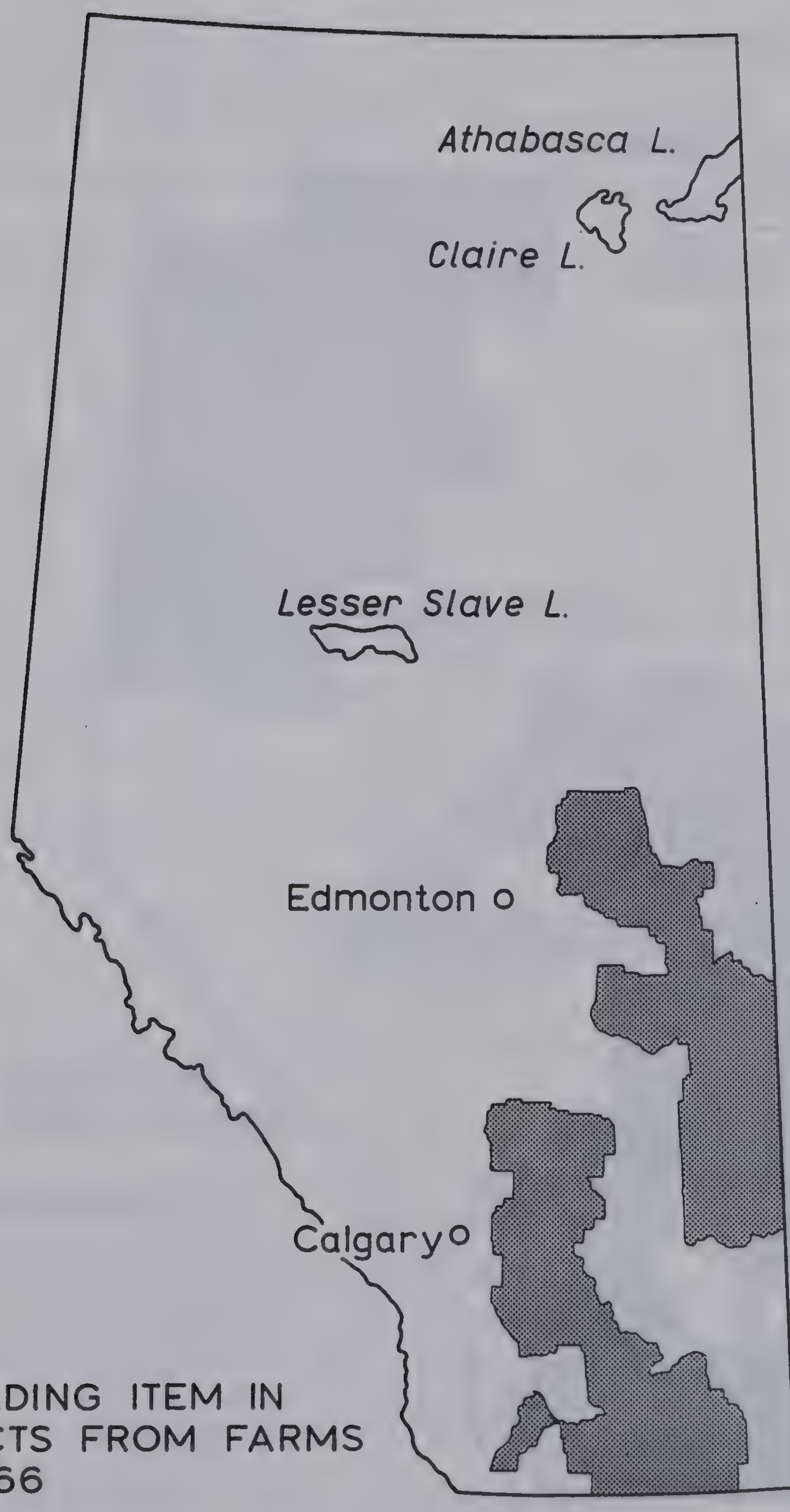
Source: Fieldwork 1969.

These figures do not, of course, reveal the major sources of income, merely the most extensive forms of land use. The classification into types of farming indicates, broadly, the principal sources of income and their relative importance. Defining a livestock farmer as one who receives 51% or more of his income from livestock and livestock products, nearly half the sample receive the major portion of their income from livestock. Almost one third of the sample obtain most of their income from cash grains and the remainder derive roughly equal amounts of their income from both sources. Of the sample classified as cereal farmers 11 do not rear any cattle at all and seven others have fewer than five cows, mainly used for domestic milk consumption, and very small numbers of other animals. For approximately 18% of the sample, farm income is almost entirely dependent upon cereal crops. In fact on 77% of the farms sampled wheat was produced, and so even for farms emphasizing livestock some land is usually given over to cereals, especially wheat. Wheat is grown on a surprisingly large scale for this area and in 1966 was the leading item in the sale of farm products for Smoky Lake County (Fig. 5.1) and contributed at least 10% to farm sales for the rest of the study area (Fig. 5.2).

Farming Type and the Frost Hazard

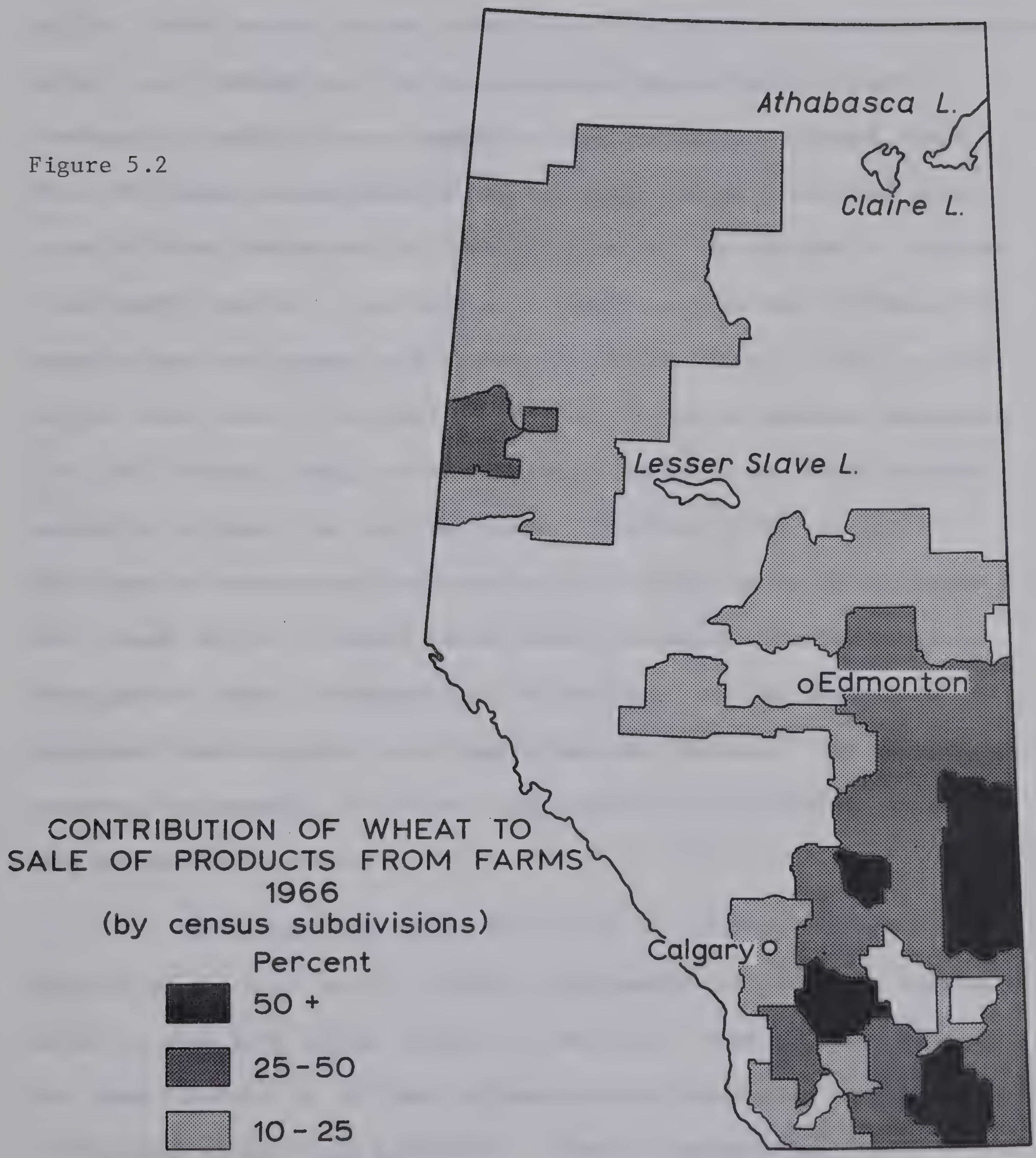
The extensive production of grains involves a considerable degree of frost risk. Of the cash crops wheat is by far the most important both in terms of income and sown area, but unfortunately wheat is also the longest season crop, of any significance, grown within the area. The livestock farmer is much less affected by the frost hazard except in terms of a long wintering period. To the livestock farmer

Figure 5.1



WHEAT AS LEADING ITEM IN SALE OF PRODUCTS FROM FARMS 1966

Figure 5.2


Athabasca L.
Claire L.
Lesser Slave L.
Edmonton
Calgary
CONTRIBUTION OF WHEAT TO
SALE OF PRODUCTS FROM FARMS
1966
(by census subdivisions)
Percent
50 +
25-50
10 - 25

moisture deficiency is an important problem, perhaps best overcome by farming extensively. However, legumes such as alfalfa are much more capable of tapping soil moisture reserves than wheat (Laycock, 1964, p. 28). With respect to the frost hazard therefore, a livestock and feed grain based economy would be most suitable for northeast Alberta. Contemporary market forces emphasize this suggestion. Hozack found that the higher income earners had relatively large cultivated acreages and were predominantly livestock farmers. He obtained a correlation coefficient of .7, statistically significant at the .01 level, by correlating farm income with numbers of cattle (Hozack, 1969, p. 117). On the other hand by the fall of 1969 Canada had in storage, including the 1969 harvest, enough wheat to satisfy domestic and trade requirements for at least the next two years (Proudfoot, 1970, p. 269). This massive over-production results in an inability to obtain markets and a real decline in wheat prices which obviously hits the marginal farm hardest since, economically, the marginal unit is defined as that unit where marginal cost equals marginal revenue. Any fall in revenue, for example, as a result of a price fall, therefore affects the marginal unit first.

The change from wheat production to livestock is not easy because of the high initial capital requirements of livestock farming, which is also more labour intensive than grain farming. The change has been hindered in the past by considerable Government encouragement to increase total wheat production. There is perhaps too, an indefinable 'traditional' (inertia) factor in the maintenance of extensive wheat cultivation. In northeast Alberta grain farmers have adjusted to declining returns by finding alternative employment and

accepting lower standards of living. Non-agricultural employment is much more important to the grain farmer than the livestock farmer (Table 5.10).

Table 5.10 Non-Agricultural Employment and Farming Types (Questionnaire Returns)

	No Off-farm employment	Off-farm employment
Grain	14	16
Mixed	16	6
Livestock	27	17

Source: Fieldwork 1969

In the spring of 1970 the Federal Government provided farmers with an opportunity to reduce their wheat acreage without total loss of income thus enabling farmers to change their practices. In the 1970 crop season farmers will be paid for summer fallowing wheat acreage.

Economically the farmer in northeast Alberta is best advised to base his operations upon livestock. This solution maximises his economic return and minimises the frost hazard. As a result of the Government decision, the 1970 crop season provides unusually good economic circumstances to reduce wheat cultivation. As yet, it is not possible to determine the effect of this decision. If, however, farmers do adapt to the physical environment given sufficient time, the regional disadvantage imposed by the frost hazard on wheat cultivation within northeast Alberta ought, in fact, to be reflected by the decreasing importance of wheat as a money earner, relative to the Province as a whole, throughout the 20th century. The agricultural censuses provide information which can be used to assess if indeed this is the case.

Agricultural Trends 1921-66

The bases of this discussion are the agricultural census returns, 1921-66, for agricultural land uses (Table 5.11) and sources of agricultural income (Table 5.12). The principal land uses missing are tame pasture, oilseed crops, mixed grains, and oats and barley grown for hay. The category 'Field crops' includes all crops that were sold off the farm, including hay, but it should be noted that in all years wheat is the single most important item in this category, usually accounting for at least three-quarters of this particular form of income for both the Province and C.D. 12. Also in this table some items have been eliminated (vegetables, fruit, forest products), but they are all insignificant to the total value of agricultural produce sold and in none of the years do these items constitute more than 5% of gross sales value. Figures have been given only for C.D. 12 and not for C.D. 13. This was because of boundary changes which made it difficult to compile data for C.D. 13 for the entire period. Before 1961 C.D. 12 was known as C.D. 13. Finally the average figures have been calculated for census farms because commercial farms were only so-defined in the 1961 and 1966 census. In the earlier part of this chapter in the comparisons between the census and questionnaire returns, the commercial farm definition was used, so that the data in the two sets of tables differ.

Identification of trends between 1921 and 1966 is complicated because of the depression years of the 1930s and the war years 1939-45. Average cultivated acreage has increased progressively, but most substantially since 1951. Field crops were dominant from an economic

Table 5.11 Agricultural Trends 1921-66

	1921		1931		1941		1951		1961		1966	
	Alta	C.D. 12	Alta	C.D. 12	Alta	C.D. 12	Alta	C.D. 12	Alta	C.D. 12	Alta	C.D. 12
Average Acreages of Principal Land Uses per Farm												
Wheat	58.9	8.0	81.5	29.4	65.7	22.2	76.1	33.0	76.9	39.6	93.7	43.2
Oats	30.7	1.4	25.3	15.5	28.6	22.1	33.8	32.9	36.0	29.9	30.1	31.2
Barley	4.7	17.3	7.2	3.1	15.8	11.6	36.0	23.0	39.1	21.6	55.9	24.4
Hay	3.1	.7	3.0	.4	6.0	2.5	14.3	13.0	33.8	23.3	42.3	42.6
Cultivated	102.8	36.9	182.2	68.7	-	-	170.9	99.1	345.4	210.4	392.9	250.4
Average Numbers of Cattle and Pigs per Farm												
Cattle	16.6	13.5	11.5	7.4	13.4	8.6	18.5	10.5	39.3	21.9	49.5	32.9
Pigs	5.1	4.7	10.8	8.6	17.1	16.1	11.0	12.6	20.0	28.6	15.7	20.5
Average Percentages of Principal Land Uses per Farm												
Wheat	57.2	21.6	44.7	42.7	-	-	44.5	33.2	22.2	18.8	23.8	17.2
Oats	29.8	3.7	13.8	22.5	-	-	19.7	33.1	10.4	14.2	7.6	12.4
Barley	4.5	46.8	3.9	4.5	-	-	21.0	23.2	11.3	10.2	14.2	9.7
Hay	3.0	1.8	1.6	.5	-	-	8.3	13.1	9.7	11.0	10.7	17.0

Source: Census, Agriculture Alberta 1921-66.

Note: Between 1921 and 1961 the present C.D. 12 was known as C.D. 13.

Table 5.12 Percentage Value of Gross Farm Revenues 1921-66 per Farm

	1921		1931		1941		1951		1961		1966	
	Alta	C.D. 12	Alta	C.D. 12	Alta	C.D. 12	Alta	C.D. 12	Alta	C.D. 12	Alta	C.D. 12
Field Crops	77.8	59.5	66.5	65.5	64.6	46.3	47.3	30.2	39.1	32.3	41.5	33.0
Stock Alive	9.3	15.9	14.7	13.9	26.5	43.8	42.8	56.5	51.1	55.7	50.2	59.1
Stock Dead	2.6	5.8	3.9	4.8	26.5	43.8	42.8	56.5	51.1	55.7	50.2	59.1
Animal Products	10.2	18.6	14.7	15.6	8.7	9.8	9.8	13.1	9.7	11.9	7.6	8.9

Source: Census, Agriculture Alberta 1921-66.

Note: Between 1921 and 1961 the present C.D. 12 was known as C.D. 13.

and land use point of view in the 1920s and 1930s for both the Province and C.D. 12, the most important single source of income being wheat. It is interesting to note that in the 1920s barley, a short season crop was more extensively grown in northeast Alberta than wheat. However, with this exception which was in any case reversed by 1931, overall trends for both field crops and the numbers of cattle and pigs have been the same for both the Province and northeast Alberta. Decreases or increases in the average acreage of any particular crop or in numbers of livestock for the Province have been reflected in similar changes within northeast Alberta. In this respect northeast Alberta can be regarded as a northerly extension of the basic Prairie economy of Alberta. Since the 1930s the agricultural economy of both the Province and C.D. 12 has become progressively diversified with livestock and livestock products becoming an increasingly important part of agricultural income, and the percentage quantity of land devoted to cereal grains becoming less.

However although trends have been similar, the extent of the changes has differed between C.D. 12 and the Province. Diversification occurred earlier and to a greater degree in northeast Alberta and by 1941 field crops comprised less than half of the farming income for this area. It was not until 1951 that the Province registered less than half of its income from this source by which time income from field crops for northeast Alberta had declined to less than one third as livestock increased in importance. Since 1951, however, trends towards a more livestock-based economy have been arrested and indeed partially reversed for the two areas. It is true that the percentage acreages of cash grains has continued to decline but this has been compensated for by increasing yields. In 1966 cash grains represented over 40% (of which

wheat accounted for 24.4%) of agricultural income for Alberta and one third for northeast Alberta. The 'revival' of wheat in the post-war period, especially in the 1960s, was undoubtedly due to abnormal market demands as a result of world food crises (Proudfoot, 1970, p. 266).

The question arises as to whether the relatively greater adjustment of northeast Alberta towards a more diversified economy was in any way a function of the temperature limitation. The similarity of the overall trends between the study area and the Province, especially in the post-war period, would suggest adjustment has been primarily economically motivated. There is not a marked structural difference in the agricultural economy of the two areas. It is noteworthy that the study area adjusted most markedly to its physical environment during the 1930s which was also a period of economic crisis. Gross farm income in northeast Alberta has been consistently well below that of the provincial average and the decline in farm income during the depression must have created even stronger pressures to diversify in northeast Alberta than in the Province. In this respect the strong trend towards diversification within the study area during the 1930s can be seen as an attempt towards self sufficiency. In 1941, the Census for the first time classified farms by type and the largest single category for C.D. 12 was subsistence (Table 5.13).

Thus, although by 1941 agriculture in C.D. 12 had apparently adjusted to a livestock-based economy to a greater extent than Alberta, this adjustment must be related, to a certain extent, to a greater need to diversify. Although since 1931 northeast Alberta has received a relatively larger percentage of income from livestock and livestock products, the income gap between the Province and northeast Alberta has

Table 5.13 Type of Farming by Income 1940

	Province		C.D. 12	
	Number of farms	%	Number of farms	%
Grains & Hay	46,619	50.9	1,479	27.6
Dairy	987	1.0	26	.4
Livestock	12,744	13.9	1,081	20.1
Subsistence	14,580	15.9	1,605	29.9
Mixed	16,575	18.1	1,162	21.7
	91,505		5,353	

Source: Census, Agriculture Alberta, 1941, Table 46.

not narrowed. Obviously the initial poverty of agriculture and the regional disadvantage even in the production of livestock are relevant factors. Also, this has partially resulted from the details of the diversification process. Since 1941 the relative importance of cash returns from swine has been very much greater for northeast Alberta than for Alberta as a whole. By 1965 pigs were the source of 44% of income from livestock in C.D. 12 and only 21% for Alberta. This results from the relative cheapness of swine to cattle in terms of both buying and feeding. On the other hand cattle generally bring in a greater financial return in the long run.

Trends in the changing farm structure of the study area have been largely determined by economic forces prevailing in the Province as a whole. However the income gap and the difference in the relative importance of livestock sales can be traced, at least in part, to the frost hazard. The area was developed later than most of the rest of Alberta and the severity of the climate imposed a considerable restriction upon settlers trying to attain an income comparable with that of

other farmers in the rest of the Province. Many of these settlers had little capital compared with others in the rest of the Province, thus being further disadvantaged. However, the question is not whether physical limitations <u>or</u> economic limitations are the real cause of marginality as suggested by Schultz (Schultz, 1966, p. 34). The two are related. Northeast Alberta was settled later and by settlers with little capital, because previous settlers had preferred to go elsewhere. This must have been because other areas suggested a more favourable physical environment to the early settlers. The late development of northeast Alberta resulted in another form of regional disadvantage in that previously settled areas already had a large input of social capital. The failure to more completely adjust to the physical environment is partly the result of an inability to finance the adjustment, itself a function of the physical base, and perhaps, partly because of a failure to perceive the implications of the physical limitations of the area in an attempt to emulate the agriculture structure of the Prairie economy as far as possible.

Farming Practices

The basic structure of the agricultural economy of northeast Alberta has been assessed as sub-optimal from both a physical and economic viewpoint. After the farmer has chosen a type of farming, decisions as to crop types and varieties used, sowing dates, harvesting practices, application of fertilisers and land use allocation, can affect the extent of the frost hazard.

Crop Types and Varieties

Wheat, barley and oats are the most extensively grown cash grains, with wheat easily the most important. The most widely grown wheat varieties are Thatcher, Park, Canthatch and Garnet; the most important barley varieties being Conquest, Olli, Parkland, Gateway and Jubilee; and the most popular oat varieties, Victory Eagle, Harman, Glen, Rodney and Onward (Table 5.14). The fastest growing varieties of the major crop types are Park and Garnet (wheat), Olli (barley), and Glen (oats). Significantly none of these is the most extensively grown. Indeed Abegeweit oats, recommended for northern areas, and Pendex oats, another recommend medium-early variety were not used by any members of the sample. The choice of wheat varieties leaves most to be desired. Thatcher, Canthatch and Manitou are all long in maturing, yet, Thatcher is easily the most popular variety. Although Thatcher is a widely adapted variety grown throughout the Prairies it is surprising that such a long maturing variety should be so popular in the study area with its short growing season. Mackintosh commented, "The general adoption of the early maturing varieties of wheat, Garnet and Reward, by 1929 greatly stimulated northern settlement" (Mackintosh, 1934, p. 187). Generally Reward is not grown anymore and as regards the study area at least, Garnet does not seem to have prevented the dominance of Thatcher, which was introduced into the Prairies in 1935. This may be because Garnet yields less and tends to produce grain of low baking quality, and in terms of quality cannot compete with many other varieties, including Thatcher. However, Park bleaches less and is easier to thresh than Thatcher (Alberta Farm Guide, 1967, p. 67) and as such would be the best variety to use, if wheat is to be grown at

Table 5.14 Crop Varieties: Reported Incidence and Days to Maturity

	Farms reporting use	Relative maturity	Days
Wheat			
Thatcher	42	Medium-late	120
Park	25	Medium-early	106
Manitou	11	Medium-late	115
Canthatch	8	Medium-late	120
Garnet	8	Medium-early	106
Barley			
Conquest	44	Medium	100
Olli	18	Early	90
Parkland	14	Medium	
Gateway	11	Medium-early	
Jubilee	9	Late	
Oats			
Victory	36	Late	110
Eagle	20	Late	110
Harman	14	Medium-late	
Glen	12	Medium-early	106
Rodney	11	Medium-late	
Onward	8	Unregistered	

Source: Alberta Farm Guide, 1967, p. 67-69: Fieldwork, 1969.

N.B. Some of these figures were corroborated and supplemented by results from the University Farm, Edmonton, as supplied by Dr. Z.P. Kondra.

all. Unfortunately Park does not yield as well as Thatcher. Manitou, a relatively new variety, which yields better than Thatcher, is distinctly stated as being late maturing in the study area (Alberta Farm Guide, 1967, p. 67). Choice of wheat varieties must therefore be considered sub-optimal in terms of the frost hazard.

Choice of barley varieties reflects much more the short

frost-free season, with only Jubilee classified as late maturing and Jubilee is eligible for feed grades only, anyway. Conquest is specifically suggested for the study area (Alberta Farm Guide, 1967, p. 69) whilst both Gateway and Olli in particular, are noted for their speed of growth. Olli, in fact is popularly known as 60-day barley and although this considerably overestimates its growth rates for the study area's latitude, Olli is the fastest growing variety available. However, neither Olli nor Gateway yield as well as many other varieties including Conquest. Because spring barley is generally faster maturing than other crop types and grows best with relatively cool temperatures and moderate rainfall, from a climatological point of view barley is the best suited cereal for the study area. Indeed spring barley is grown farther north and at higher elevations than any other spring cereal (Leonard and Martin, 1963, p. 484). Schultz implies soil is frequently a restricting factor to barley cultivation within C.D. 12 (Schultz, 1966, p. 39). However of all the physical factors of plant growth, soil is the most readily altered. In any case barley is grown very extensively over C.D. 13 where the soils are similar to those in C.D. 12.

As regards oats, Eagle and Victory are the two most widely grown varieties despite the fact that they are late in maturing and with little resistance to stem rust. Abegeweit, which has a greater resistance to stem rust, is shorter maturing and yields just as well but is noticeably absent from the study area. Ajax, the fastest growing oats, is also absent but this variety yields rather poorly. It is difficult to comment on the use of Onward, an unlicensed English variety, which has no record of performance in Western Canada. There is no doubt that

the frost hazard could be decreased by a more selective choice of oat varieties.

Many reasons were put forward by farmers for particular choices of crop varieties although the most frequent comments generally referred to the yield, and very few to the relative rates of maturity. Some varieties were used merely because they were the only ones available at the time and place of purchase. However, there does seem to be an historical factor involved. Thatcher wheat, Conquest barley and Victory and Eagle oats are all old varieties with a considerable history in Western Canada. The contemporary choice of varieties seems to a large extent to be the choice of the previous generation. There have been no new varieties that have increased yield as well as shortening the growing season. Olli and Gateway barley, in fact, tend to produce lower yields. If farmers do judge new varieties on the basis of yield mainly rather than on the rate of maturity, then the incentive to change will be reduced. The relative importance of Park wheat and Olli barley suggests there is some degree of concern for the rate of growth. There is no doubt too, that farmers experiment with the varieties available. Apart from the main crop varieties already tabulated, six more varieties of wheat, six varieties of barley and a further four varieties of oats were reported by the sampled farmers. It is postulated that change to faster maturing varieties would be greater if yields were also improved over and above the existing crop types.

Throughout the study area adjustment to the frost hazard as illustrated by the most popular crop varieties must be regarded as sub-optimal especially in the case of wheat and oats. As regards the major land uses there are broad regional variations which have already

been noted. Because of the greater emphasis upon tame pasture, grasses and barley, the sample areas within C.D. 13 are ecologically better adapted to the physical environment. This is particularly true for the Newbrook sample area. On the other hand the leading sample areas in wheat and oats production are within C.D. 12.

Sowing and Harvesting Practices

Dates of seeding vary from year to year according to the nature of the spring but for long season crops such as wheat, this variation cannot be very much. Very early seeding would involve too high a spring frost risk whilst late seeding would create a severe risk in the fall. Seeding dates, especially for wheat, in any particular year are likely to be more typical of the average than the harvesting dates of any particular year, since the date of harvesting is affected by any phenomenon which affects the crop during the entire length of the growing season. There is also a greater probability of a delay in harvesting due to rainfall than a delay in spring seeding. Wheat, and flax where grown, are generally seeded first, followed by oats, and finally barley and rape are usually sown about the same time. The shortness of the frost-free season obviously dictates this crop sequence. Within the study area wheat is sown, on average, between May 15 - 19 whilst barley is usually sown in the first week in June (Table 5.15).

Seeding dates for barley are much more evenly spread than those for wheat indicating a greater freedom in dates of sowing for faster maturing crops. If wheat is sown on May 15 then the crop may be expected to be physiologically mature, assuming the crop is grown on summer fallow, by August 19 (Park) or September 2 (Thatcher).

Table 5.15 Sowing Dates for Wheat and Barley (Questionnaire Returns)

WHEAT	Pre May 10	May 10-14	May 15-19	May 20-24	Post May 24	
Farms Reporting	3	13	22	23	7	
BARLEY	Pre May 25	May 25-31	June 1-5	June 6-10	June 11-15	Post June 15
Farms Reporting	6	12	12	12	12	4

Source: Fieldwork 1969.

Seeding by more than a few days before May 15 cannot be expected to forward the harvesting dates, since the delays (and perhaps damage) caused by the higher incidence of frost may more than offset earlier sowing times, and also temperatures in early May could be too low for growth anyway. Seeding by more than ten days after May 15, however, delays physiological maturity for even the faster growing wheat variety (Park) until the end of August when the risk is 50% for many areas and approaching this probability level for most areas. The best solution is to sow Park wheat around May 15. As regards Thatcher wheat there are just not enough frost-free days for this variety to grow free of frost, every year or even every other year.

Barley has a much greater chance of growth free from frost. Olli, for instance, may be sown on June 1 and still be expected to be physiologically mature by August 19 whilst Conquest sown on the same date reaches a similar stage of growth by August 29. Most barley is sown after June 1 and a good deal after June 10. Only Olli barley has any chance at all of reaching maturity before the first fall frost after such late sowing. Barley is sown so late because of its speed of maturity, its preference for high soil temperatures, because wheat

and oats have to be sown first and because, like rape, it is slightly more susceptible to spring frosts. However, such late seeding imparts to barley, especially Conquest and other medium maturing varieties a higher degree of frost risk in the fall than need necessarily be the case. Neither barley nor rape is supersensitive to spring frosts and it might be a wiser practice to seed Conquest barley around May 25 and to seed only Olli after June 5. Given the speed of maturity of most varieties, and the plant's general climatological requirements, barley offers to northeastern Albertan farmers the best chance of producing extensive quantities of a high quality cereal, always assuming soil conditions are suitable. Similar comments can also be made about rape, which is, at the moment, a cash crop in demand.

Oats are sown after wheat and before barley or rape and an approximate average date for sowing would be May 25 which means that Victory oats should be physiologically mature by September 2 and Glen oats by August 27. Such dates involve a high degree of frost risk in all areas, although oats are slightly more frost resistant in the fall because of their hard shell.

Most sowing of any crops occurs after May 15 at which date there is still a more than 50% of frost in all areas. Therefore it cannot be recommended that sowing start earlier. Even at this date most wheat and oat varieties will not mature till early September. After the first week in June only Olli barley has a chance of growing frost-free. However, in whatever way sowing dates are manipulated it must be concluded that the frost-free season is insufficient to permit extensive cultivation of many of the most popular varieties of wheat and oats free from frost at both ends of the season. Whenever wheat,

oats and barley are grown on the same farm the present distribution of sowing dates cannot be readily improved upon in terms of the frost hazard. Thus short season crops are relegated to late seeding dates and as a result frequently have a similar fall frost risk as the longer season crops.

In assessing the viability of the above crop varieties it has been assumed that on reaching physiological maturity, the crops are immediately swathed thereby reducing the frost hazard considerably. The alternative is to leave the crop standing and wait for agricultural maturity and then to straight combine, a practice which considerably increases the frost hazard. In fact only a few farmers straight combine and swathing can be regarded as a universal practice in the study area. However, the precise time at which to start swathing can vary by at least ten days and is, in any case, open to a wide range of interpretation by individual farmers. It is a question of moisture content and some farmers prefer to wait longer than others. Furthermore, the date of physiological maturity can be delayed by lower than usual heat units during the growing season, moisture deficiencies and occurrence of frost. Harvesting operations can be further delayed by heavier than normal rain in August and September.

If the dates of physiological maturity quoted above are when farmers would like to start swathing, harvesting dates for 1968 and 1967 suggest that this does not necessarily actually happen (Table 5.16).

The 1967 harvest was associated with comparatively dry weather whilst the harvest in 1968 was accompanied by abnormally wet weather. As a result harvesting started later, lasted longer and finished later in 1968. An average date for the start of the 1968

Table 5.16 Harvesting Dates 1967 and 1968
(Questionnaire Returns)

1967 Start of Harvest						
	Pre Aug. 31	Sept. 1-10	Sept. 11-20	Sept. 21-30	Oct.	
Farms Reporting	29	27	16	8	2	
1967 End of Harvest						
	Pre Aug. 31	Sept. 1-10	Sept. 11-20	Sept. 21-30	Oct.	
Farms Reporting	1	5	12	22	39	
1968 Start of Harvest						
	Pre Aug. 31	Sept. 1-10	Sept. 11-20	Sept. 21-30	Oct.	
Farms Reporting	15	25	14	20	10	
1968 End of Harvest						
	Sept. 21-30	Oct. 1-20	Oct. 21-31	Nov.	Dec.	Spring 1969
Farms Reporting	7	9	27	36	9	2

Source: Fieldwork 1969.

harvest would be between September 11-20 whilst an average date for the end would be in early November. Similar dates for 1967 are the first week in September, and the end of September - beginning of October. It is noticeable that under the more 'normal' harvesting conditions of 1967, most of the harvesting had still not been completed by September 21. Approximately one-third of the farmers who reported harvesting dates in 1967, did not even start to harvest until September 11. Harvesting operations well into September and October should not therefore be regarded as unusual. The lateness and prolonged duration of harvesting in this area confirms the physical limitations with which agriculture has to contend, and the unsuitability of long season crops. In 1967, when the frost-free season, heat units and moisture distribution

were at least average, the dates of physiological maturity (and therefore the potential dates for swathing) must have occurred on the whole at least slightly later than the 'expected' figures quoted above. Even these expected values involve a considerable degree of frost risk.

Summer Fallow, Fertiliser and Seed Quality

In deriving the dates and number of days for each stage of growth, an assumption was made that the crops were grown on summer fallow and seed of an acceptable quality was used. Crops grown on summer fallow tend to grow faster and yield better because of weed control, the build up of plant nutrients and conservation of soil moisture. Summer fallow is generally used for wheat cultivation in the following year. In recent years the role of summer fallow has been primarily realised as one of controlling weeds. Within the study area, if the land is not summer fallowed the land has to be worked over several times in the spring to eliminate weeds before a crop can be sown. This is another reason why wheat is generally sown first, since if wheat is grown on summer fallow, the seeding of other crops has to wait land tillage. Weed control frequently delays the sowing of oats and barley until late May and early June. In this respect summer fallowing is a necessity for a long season crop such as wheat which has to be sown as soon as possible. In the percentage use of cultivated acreage, Lac La Biche, Iron River and Vilna are noticeable in their high wheat wheat to summer fallow ratios. In the other areas summer fallow is equal or very slightly more extensive than wheat.

Apart from the areas indicated above, it seems fair to assume wheat is grown over large areas on summer fallow, but with a few

exceptions, this assumption is largely erroneous for other crops. The property of summer fallow of building up plant nutrients is of little importance because of the availability of fertilisers. Fertilisers, if the correct kinds are used in the right amounts, and if there is a favourable distribution of rainfall, will increase yields, may improve quality and could result in maturity by as much as ten days earlier. Virtually all of the fertilisers used in northeast Alberta contain a certain amount of nitrogen, although some contain more phosphates than nitrogen. Because nitrogen produces rapid growth in cells thereby decreasing frost resistance care must be taken with nitrogen application at planting time. Predominantly nitrogen fertilisers should, preferably, not be applied with the seed, but a little later although this will lead to an increase in the cost of production. In the use of fertiliser 50% of the farmers sampled are regular users, a third do so occasionally and over 16% have never used fertiliser. Fertiliser application has still not, therefore, found universal acceptance within the study area. These figures are very surprising considering the relatively poor soils of the area and the limited growing season where speed of growth is absolutely essential. To obtain the full benefit from fertilisers they must be applied every year because, in any one year, potential return may be negated by, for example, lack of spring moisture or frost damage.

There is no doubt that high prices of fertiliser in association with the short term variable return is an important factor in the low degree of fertiliser application. Also increasing production in the West has been traditionally associated with expansion of area rather than yields. Theoretically it can be argued that marginal areas

tend to be the last to adopt or innovate, this being partly why they are marginal. In order to obtain the best results possible summer fallowing and fertiliser application ought to be associated with the use of the highest quality seed. Of the sample 20% regularly used Pedigree or Certified seed whilst a further 31% used such seed occasionally. Approximately 14% bought seed largely from a seed cleaning plant, whilst fully one-third used poor quality old seed or they were not sure from where the seed came. As regards seed changes 8% regularly changed every year, 10% every two years, 42% every three-four years and 37% changed after five years or more. Summer fallowing, careful use of seed, and fertiliser application especially are agricultural practices which can reduce the frost hazard. Unfortunately none of these practices is utilised to achieve maximum benefit.

Land Use Allocation

Frost risk, both in intensity and frequency, varies according to the sum of topographic effects. The spatial variation of frost ought therefore to be reflected by similar patterns in land uses so that the short season crops are grown in the localities where the frost hazard is potentially great. In areas where the relief variation is most marked, for example in the Meanook and Rochester sample areas, there is considerable evidence for this type of adjustment. In the valley of the River Tawatinaw, a small stream in a steep sided valley, wheat cultivation is virtually absent whilst pasture, barley and occasionally rape were the most frequent uses. This valley is an obvious 'frost pocket' but even so one of the sampled farmers in the Meanook area had sown wheat there in 1969 because he had summer

fallowed the land in the previous year, although he did realise the degree of frost risk this involved.

For the most part, however, there is not such a sharp distinction in frost hazardousness as between plateau top and valley bottom. High land in the form of ridges is frequently wooded because of soil and moisture problems. Extensive tracts of land at a relatively high level are generally rare, Elk Point sample area being an exception. The larger part of the Newbrook sample area is just the opposite. It is perhaps significant that this area produces less cereals including wheat, than any other area. Extreme frost risk can be created by very gentle gradients, even within relatively high areas. Relief undulations are such that large fields will encompass both relatively high and low land. There are therefore a number of physical reasons that militate against complete land use adjustment to spatial variations in frost risk. In any case such land use adjustment tends to create a frost risk for short season crops similar to that of long season crops.

Agricultural Practices and the Frost Hazard

In northern areas agricultural practices should be primarily geared to the short growing season. Broadly speaking the physical limitations of the area suggest hay and forage crop production for livestock feed. Of the cash crops barley and rape are the most suitable. Barley has been historically important in advancing the northern margin of agriculture in both North Europe (See Fullerton, 1954) and Canada and was generally the first crop to be sown in northern areas. At the present time barley sold for malting purposes can bring

in a relatively high return. Potatoes, a widely adaptable crop is a significant item missing from the agricultural economy of the study area. The extensive production of wheat particularly indicates the need for a structural adjustment in the farming economy. In terms of the frost hazard the cultivation of wheat is unfortunate on three counts. Firstly this area cannot compete as regards yield and quality with other areas in wheat production. Secondly wheat tends to be produced on land where the frost hazard is least so that other crops, notably barley and rape, which would stand an acceptable chance of success on the same land, are relegated to low lying areas where the frost hazard is frequently extreme. Lastly if summer fallow is available wheat is generally sown on it, so that other crops can often only be sown after weeds have been laborously cleared. This narrows down considerably the choice of sowing dates for these crops, although this point is of little significant importance if such crops are to be sown on low land. The widespread production of wheat represents the largest single maladjustment of the farming community to the physical environment of the area.

Apart from this, in making adjustments to the short growing season the sampled farmers were found to be particularly inefficient in their application of fertilisers especially, but also to a large extent in their choice of crop varieties. Selection of quick growing varieties and the careful, but permanent use, of fertiliser can reduce by several days the time taken to maturity in an area where even a few days can be crucial. Finally the frost hazard expresses itself in the form of economic returns. The relatively low incomes in this area are an indication of the maladjustment of farming to the environment and

the comparative disadvantage of this area. Historically the colonisation, settlement and ultimate success of new areas depends upon the interplay of economic and physical forces.

"There is no question that a period of high prices for agricultural products would extend agricultural settlement and wheat growing far to the north. Settlement takes place for exceedingly diverse reasons, of which by no means the most important are economic; settlement persists, however, only if satisfactory incomes can be earned. Adverse physical environment, frost risk, inferior soil, scanty pasture and long transportation hauls reduce incomes, but if prices are sufficiently high such reductions may be offset" (Mackintosh, 1934, p. 187).

However, settlement can and does persist even when satisfactory incomes are not being earned. When prices fall agricultural settlement cannot just 'disappear'. Inertia, problems in migrating, inability to find alternative incomes either because of age, lack of non-farm skills or lack of alternative employment deter such immediate adjustment. In North Sweden the margin of agriculture has been considerably pulled back as a result of strong Government pressure. In Canada, Government pressures have tended to work in the opposite direction and northern marginal rural areas constitute one of Canada's regional problems.

CHAPTER VI

FARMERS' PERCEPTION OF THE FROST HAZARD

The decisions made by farmers in response to the frost hazard must be a function of the manner in which they perceive the frost hazard. If further adjustments are to be made it is necessary for farmers both to recognise the problem and the solutions. If proposals are to be suggested to reduce the frost hazard it is important to relate these proposals to the significance farmers attach to the frost hazard. Before further commenting on farmers' perception of the frost hazard and hazard reducing techniques, it is pertinent to clarify some definitional problems and theoretical aspects, and briefly review the relevant literature.

Perception

Currently there is not a single, commonly accepted definition for geographic perception, which is in part a reflection of the recent rapid rise of perception as a research concept and in part because of the complicated nature of the perceptual processes. Basically perception studies in geography seek to show a relationship between the milieu, defined as "the totality of environing factors" (Sprout, 1956) and the way in which men view the milieu. This has been simply put by Lowenthal as "the relationship between the world outside and the pictures in our heads" (Lowenthal, 1961, p. 241). Some of the more important perceptual processes by which individuals create mental images

of the milieu include experiences, memories, dreams, thoughts, learning and images. Culture and personality are also significant formative elements in any individual's perception. Perceiving then is a cognitive process by which individuals create mental maps of the world, and geographical studies attempt to show relationships between the perceptual (mental) environment and the objective geographical environment.

'Maps' or images, as a result of the perceptual processes, of the external, visual and geographical environment are only a part of the total mental image. The anthropologist, Wallace has coined the term 'mazeway' to include all the complex, dynamically interrelated mental images contained by each individual's brain (Wallace, 1962, p. 16). The mazeway can be classified on a threefold basis to include: values held, images of objects both animate and inanimate, and images of the techniques available to control objects in order to obtain some desired values. Each of these phenomena can be subdivided. For example, 'Objects' consist of body images, self images, the human environment, the non-human environment, the supernatural environment and statements about how the entire socio-cultural, self, natural and supernatural system works. The classification can be taken even further. Thus the non-human environment would include images of animals, plants, tools and equipment, natural phenomena, and the natural system as a whole (Wallace, 1962, pp. 16-19). This classification may, in fact, provide a framework in which all perception studies in all disciplines can be related. The significance of the mazeway concept to this discussion is to place the perception of frost, as only one element of natural phenomena, in a proper perspective in terms of the total 'images' held by farmers.

To identify patterns, spatial or otherwise, in the perceptive processes with regard to a particular element of the physical environment, it is absolutely essential that the particular element in question be defined as thoroughly and as objectively as possible. Thus to reveal farmers' perceptions of the frost hazard, the frost hazard must be understood first. This is another reason for the format of this thesis.

Personality and Culture

The two concepts of personality and culture are inseparably linked to the perceptual processes and a discussion of them can help justify the apparently contradictory statement: the uniqueness of individual perception and the generality of human behaviour. Lowenthal notes, "the life of each individual constitutes . . . an original and irreversible perceptive experience" (Lowenthal, 1961, p. 251). He suggests two forces which lead to generalities in attitude and behaviour: necessity and culture. Necessity is explained by the argument that perception of the environment must be in fair accordance with reality, or else man would not have been able to survive and thus, by implication, people with a common environment share at least same basic views. Similarly culture "screen[s] perception of the milieu in harmony with its particular style and techniques" (Lowenthal, 1961, p. 252). Lynch would agree with the force of necessity when he says group images must exist, "if an individual is to operate successfully within his environment and . . . co-operate with his fellow men" (Lynch, 1961, p. 46).

Wallace suggests more sophisticated reasoning, involving the thorny concept of personality to explain the link between unique private perceptions and common behavioral traits (Wallace, 1962).

He regards personality as a more abstract form of mazeway, involving an individual's motives and desires. The mazeway is a statement of all the mental images of the brain, and according to Wallace, it is the collection of mazeways that constitutes culture whilst personality is unique to every individual. The mazeway via the perceptual processes provides the link between personality and culture. Wallace suggests two reasons to explain the existence of common culture and at the same time justify the maintenance of individual personality.

The first is simply stated as the replication of uniformity which is a measure of the degree to which one generation attempts to be similar to the preceding one. The second argument involves the organisation of diversity. This states that although each individual's motives and desires (basic elements of personality), and even cognitive mental maps may be different, groups of people, "organise their strivings into mutually facilitating equivalence structures" (Wallace, 1962, p. 28). This means that common themes exist within a society not because of uniformity of internal desires and images, but as a result of an individual's capacity to predict the behaviour (not the motives) of other individuals within a group (or culture). Equivalence structure means that behaviour is mutually predictable and equivalent, usually as a result of implicit contracts (to use Wallace's example, the driver of a bus and his passengers). It is culture that is shared and not personality, culture making possible, "the maximal organisation of motivational diversity" (Wallace, 1962, p. 41). In fact Wallace sees two advantages in cognitive non-uniformity. Firstly, such non-uniformity allows a more complex system to develop than any of its individual members can understand in total, and secondly, cognitive non-uniformity

liberates individuals within a system from the tension of knowing each other's motivations. These arguments provide the theoretical justification of this discussion in that interpersonal diversity is matched with "the complementarity of perceptions in physical observation" (Wallace, 1962, p. 29).

This chapter considers only a small aspect of individual farmer's mazeways and that is the perception of a particular aspect of the non-human environment, frost, and the techniques capable of manipulating this hazard. According to the above account, common themes ought to be present in farmers' perceptions of the frost hazard within the study area, because of the similarity of the milieu and of experiences, although this will not necessarily shed light upon each individual's motives, or the broader aspects of each farmer's mazeways. The bases of the analysis of farmers' perceptions are the verbal responses to a questionnaire. There are, however, semantic problems in the use of such terms as 'attitude' and 'opinion'. As far as this thesis is concerned when orally expressed opinions of a large number of individuals, isolated in time and space, are similar, then this illustrates basic attitudes.

Review of Natural Hazard Perception Literature

Perception studies are not new in the sense that 'cultural appraisals' and 'regional consciousness' have long been basic themes within regional geography. Cvijic, a Serbian geographer, stated 50 years ago,

". . . We consider, therefore, an important aim of geography to be the determination of the psychological character of the population

in different geographical regions and to indicate the part which geographical conditions took in the formation of this character" (Campbell, 1968, p. 247).

Jean Brunhes felt that, "Every fact of human geography conceals and implies a psychological problem" (Brunhes, 1913, p. 365). However, the application of the concept of perception as a research tool is of much more recent vintage and represents the first time any significant influx of psychological ideas into geography has occurred (Sims and Saarinen, 1968, p. 678). Techniques that have been used within the last decade in natural hazard perception studies include thematic apperception tests (Sims and Sarrinen, 1968), content analyses of news media (Rooney, 1967), structured and unstructured questionnaires (Roder, 1961), benefit-cost analyses (White, 1964), models of decision-making (Kates, 1962), whilst new uses of probability theory have also been suggested (Hewitt, 1968). All this is part of an increasing effort to measure more precisely the relationships between physical environment and human behaviour.

In some cases considerable emphasis has been placed upon physically defining the hazard in question as objectively as possible. These studies illustrate the need to comprehend fully the physical dynamics of the hazard before it is possible to determine in any meaningful way the behavioural responses to the hazard. Saarinen, for example, used Thornthwaite procedures and the more recently developed Palmer drought index in order to assess in non-subjective terms, the frequency, duration, severity and spatial variation of the drought hazard upon the Great Plains (Saarinen, 1967). Rooney, in order to justify his hierarchy of disruptions in a study of the urban snow hazard,

investigated depth and rates of snowfall, water content of the snow, wind speed at time of snowfall, and the associated temperature conditions (Rooney, 1967).

One of the reasons for the sudden surge of interest in natural hazard perception studies is the increasing socio-economic costs of such extreme geophysical events (Burton, Kates and White, 1968, p. 3). However, there appears to be growing faith in technology over the forces of nature and despite increasing awareness of the risks involved, there is still constant re-occupation and expansion of hazardous areas. For example, the population of the Fraser flood plain, British Columbia, has doubled since 1948 when a devastating flood caused compensated losses of over $20 million (Sewell, 1965). Within Alberta official government policy still encourages homesteading in some northern areas despite agricultural surpluses, rural poverty and extremely low chances of success in such marginal areas. In terms of migrating from hazardous zones Roder has noted that there may be strong economic and social forces preventing private individuals from moving to another area (Roder, 1961).

Underestimation of both the intensity and frequency of hazards is a general finding in most studies, from farmers' perception of drought (Saarinen, 1966) to temporary coastal dwellers' attitudes on the shores of megalopolis (Burton and Kates, 1964). This underestimation characteristic is often associated with future optimism. For example, wheat farmers in Australia responded to the severe drought losses of 1965 by planting an increased acreage in 1966 in the hope of a better season (Heathcote, 1969, p. 187). The perceived frequency of hazards seems largely a function of experience and memory. On the drier margins

of the Great Plains, farmers tended to perceive the frequency and intensity of drought more accurately than farmers in the more humid areas. Of particular importance was recent past experience. Small November showers induced farmers to have greater optimism as regards the possibility of drought in the forthcoming year (Saarinen, 1966, p. 68).

Experience of observers may affect the registration of a hazard (Heathcote, 1969, p. 182). A Canadian Government pamphlet issued in 1881, encouraging settlement in the West, stated, "The story of summer frosts in the N.W.T. has long since exploded . . . any farmer can make himself perfectly secure from loss, by taking care to sow his seed as early as possible in the Spring" (Canada, Department of Agriculture, 1881, p. 44). This statement was made before any extensive colonisation had occurred in either Alberta or on the present margin of cultivation.

Perception studies have generally failed to isolate personality as an independent variable in the perceptive processes. It has been suggested that the thematic apperception test may be used to isolate personality as a factor in areal differentiation, as well as revealing insights into the role of personality within the decision-making process in the face of crisis (Sims and Saarinen, 1968). It would seem, however, that considerable refinement of research tools is necessary before the abstract concept of personality can be 'measured' with some degree of accuracy. Socio-economic variables frequently considered in perception studies include education levels, degree of innovativeness and whether the individual is professionally or non-professionally involved with the hazard. As regards the latter, one of the major differences seems to be in the tolerance of uncertainty, common responses to uncertainty by the

non-professional being to eliminate the hazard or eliminate the uncertainty (Burton, et al., 1968, pp. 15-18). A variety of studies has suggested a relationship between perception of a hazard reducing technique and the eventual adoption of the technique (for example, Saarinen, 1966, p. 92). However whilst simulation studies have provided considerable empirical evidence for the role of social contact in the diffusion process, the precise significance of perception has not yet been ascertained.

Adjustment to extreme natural hazards has tended to be crisis motivated, especially in the public sector, and aimed at the effects rather than the causes of hazards. Thus adjustment to drought in Australia is still largely in the form of massive Government relief whilst insurance, conservation of fodder and the restriction of land use are practically non-existent (Heathcote, 1969). Sewell has noted similar trends in flood adjustment, where despite a wide range of possible hazard reducing techniques, particularly integrated river basin development, there has been concentration on a relatively narrow range of adjustments, with very little introduction of new innovations (Sewell, 1965). Not all adjustments have been crisis motivated, however, and there does seem to be a wide range in behavioral response in the face of uncertainty. Rooney, for example, found that the operational plans to offset the snow hazard in Green Bay were more than adequate and were set in motion during the snowfall. In other places, such as Rapid City which has the same snow hazard as Green Bay, public action was virtually non-existent and adjustment was left to each individual. To explain this wide variation in behavioral response, Rooney suggests the satisficer concept, the esthetic values of snow, lack of knowledge on the cost of snow disruption, and perception of the snow

hazard (Rooney, 1967, p. 557).

The following analysis of farmers' perception of the frost hazard will complete an holistic intepretation of the frost limitations for agriculture in northeast Alberta. An attempt will also be made to relate the findings of this chapter to other natural hazard perception studies.

Measurement

Perhaps the biggest difficulty facing perception as a research tool within geography is one of measurement. On this, Rooney, for one, would concur (Rooney, 1967, p. 557). Evaluation of the relationship between the mental images of farmers' minds, formulated as a result of complex, cognitive processes, towards the frost hazard, and an holistic definition of the frost hazard, must be stated in qualitative terminology. The only data available to make this assessment are the attitudes expressed by farmers to certain questions. It is the relationship between the attitudes expressed and the defined hazard that indicates the degree of perceptiveness. Any problems the sampled farmers may have had in articulating their thoughts, either because of linguistic impediments or because they were unwilling to do so, increase the difficulty of measurement. Once the verbal expressions have been noted, the answers have to be coded and classified. This is particularly difficult for open ended questions. In this sense evaluation of farmers' perception of the frost hazard is an exercise in marking, comparable to giving credit for examinations.

Perceived Frequency of Frost Damage

Farmers were asked to estimate how many years in ten they would receive frost damage of some sort. The full range of possible answers was received for the question although 69% of the sample thought frost damage resulted in between one and five years out of ten (Table 6.1).

Table 6.1 Estimated Frequency of Frost Damage % Response

Years out of 10	0	1	2	3	4	5	6	7	8	9	10	Don't know
% Response	6.1	15.2	15.2	17.2	13.1	9.1	2.0	2.0	5.1	1.0	9.1	4

Source: Fieldwork 1969.

Only the most general comments can be made about this distribution. Those farmers who estimated a very high frequency of frost damage generally emphasized that only quality was reduced in most years. The modal category is three years out of ten which gives a degree of evidence for previous conclusions derived from climatological data. In fact in the cases where farmers could remember, with one exception, the years most noted for frost damage were 1968, 1959 and 1965. These were the years with the lowest number of heat units and the shortest frost-free seasons. The one exception was in 1966 when a large farmer in the Iron River area reported extensive yield losses due to an early August frost. For the most part, individual farmers could not remember more than one year which was bad for frost, no matter how frequent they estimated frost damage. Virtually all farmers expect some frost damage in ten years, a reflection of the extensive production of cash grains. Estimates of frost damage showed little relationship with any other variable including type of farming, area location, expectancy of first

fall frost, production of wheat, and estimated length of the growing season. Particularly surprising is the lack of association between estimated frequency of frost damage and expectancy of first fall frost (Table 6.2).

Table 6.2 Frequency of Frost Damage and Expectancy of First Fall Frosts

	Years out of 10							
	No Damage	1	2	3	4	5	Over 5	'Don't knows'
Aug. 15-20	18.8%	-	25.0	6.3	12.5	12.5	18.8	6.1
Aug. 21-31	3.4	20.7	13.8	17.2	13.8	-	30.9	-
Sept. 1-1-	7.1	7.1	7.1	14.3	14.3	35.7	7.1	7.1
Sept. 11 +	5.9	17.6	5.9	41.2	-	-	17.6	11.8

Source: Fieldwork 1969

This notable lack of any significant relationship occurs despite the fact that over 75% of the sample considered a fall frost to be more damaging than a spring frost. Of the 79 farmers who replied, over half considered the first average frost to occur in August (Table 6.3).

Table 6.3 Expectancy of First Fall Frost %

August 15-20	August 21-31	September 1-10	September 11 +
21.5%	36.7%	17.7%	21.5%

Source: Fieldwork 1969

There are slight differences in the sample areas, farmers in the Athabasca, Iron River and to a lesser extent, Elk Point sample areas considered the first frost more likely to occur in September. The other areas,

but notably Newbrook, thought August to be more probable. Effect of spring frosts was thought to result mainly in a delay in maturity, although a few considered that the severity of the 1969 spring frosts would reduce yield. Some thought a frost 'at the right time' would lead to increased stooling and a better crop. There is some evidence that frequency of frost damage is underestimated. Of the 75 farmers growing wheat only 14 estimated damage in more than five years out of ten, whilst two did not report any loss, and 25 reported losses in only one or two years out of ten. Although damage will obviously vary with the land situation and wheat variety used, it is probable that for some farmers wheat quality is not related to the short frost-free season.

Farmers' Observation of Frost Occurrence

The selectivity of frost occurrence and the associated synoptic conditions are well understood by all farmers. Susceptibility of low areas and muskeg are universally known facts. The major weather conditions associated with frost, calm winds and clear skies, are likewise well known (Table 6.4).

Table 6.4 Associated Weather Characteristics of Frost Occurrence

	Calm	Clear	Wind	After Rain	Moon
Farmers Reporting	88	94	15	36	23

Source: Fieldwork 1969.

The high incidence of farmers reporting wind is regarded as being due to the timing of the interviews, which were immediately after the advection frost of mid-June, 1969, with its associated northerly winds.

This emphasizes the importance of the recent past in cognitive processes. Farmers reporting both wind and calmness suggested a fall in wind speed during the night when the frost actually occurred. The relatively high percentage of farmers who associate frost with the moon (usually the full moon), and after a period of rain is interesting. Suggestion of a correlation between the moon and frost must be related to superstition. Those who postulate frost occurs after rain argue that rainfall results in cooling, thereby creating a higher probability of frost. As regards the hypothesis that abnormal May rainfall results in a lack of June frosts, farmers were in general disagreement. Even for those who said this might be the case, it was obvious that the farmers had not previously heard of this hypothesis.

Perception of Frost Damage

Assessment of farmers' perception of frost damage is based upon their knowledge as to how many degrees of frost is required to damage wheat, oats and barley. A separate assessment was made for those farmers who did not grow all these crops, and in the following tables these answers are bracketed. The answers required farmers to acknowledge that frost resistance varies throughout the growing season and to indicate temperatures of approximately the right order of magnitude for three stages of growth. These stages of growth were early spring (approximately 10 degrees F of frost), early fall (2-4 degrees F of frost), and late fall (4 degrees F of frost approximately). Farmers were then graded into four categories, number one representing the best and number four the worst perceivers. The rationale behind the classification was as follows:-

Category	Answer
1	Recognition of stage of growth and good idea of degrees of frost required.
2	Recognition of stage of growth but good idea of degrees of frost required for only 1 crop or 1 particular stage.
3	Recognition of stage of growth but little idea of temperatures involved.
4	Failure to realise importance of stage of growth and little idea of temperatures. This category also includes the 'don't knows'.

The main difficulty in following these rules was in distinguishing between categories 2 and 3. Very few farmers were placed in the highest category (Table 6.5).

Table 6.5 Perception of Frost Damage

	1	2	3	4
% Farmers	11.5(10.1)*	22.9(18.2)	37.5(41.4)	28.1(30.3)

Source: Fieldwork 1969 *(-) farmers not growing all grain crops.

There are good relationships with perceptiveness of frost damage and various socio-economic indexes, not including education and ethnicity. Education levels for most farmers were low and generally not beyond junior-high. The similarity of formal educational background prevented any relationships between education and other variables being achieved, if indeed there are any such relationships. Parental origin and country of birth were not found to be significant in perceptiveness of frost damage. This is not surprising since the last extensive migration into

Table 6.6 Farm Size (acres) and Perception of Frost Damage

	1-320	321-799	800-1000	1000+
1	1	4	1	5
2	5	6	6	5
3	7	14	6	9
4	8	11	4	4

Source: Fieldwork 1969.

Table 6.7 Cultivated Acreage and Perception of Frost Damage

	1-120	121-350	351-700	701 +
1	0	2	8	1
2	4	7	8	3
3	3	19	11	3
4	5	10	11	1

Source: Fieldwork 1969.

Table 6.8 Farming Type and Perception of Frost Damage

	Cereal	Mixed	Livestock
1	2 (1)*	4 (4)	5 (5)
2	7 (5)	2 (2)	13 (11)
3	10 (12)	9 (9)	17 (20)
4	11 (12)	7 (7)	9 (11)

Source: Fieldwork 1969.

* (-) farmers not growing all grain crops.

Table 6.9 Alternative Employment and Perception of Frost Damage

	None	Full-time	Summer Part-time	Winter Part-time	Part-time
1	10	1	0	0	0
2	12	5	1	4	0
3	18	12	1	2	3
4	16	5	0	5	1

Source: Fieldwork 1969.

Table 6.10 Visits to District Agriculturalists and Perception of Frost Damage

	Never	Once p.a.	2-3 times p.a.	Over 4 times p.a.
1	2	1	4	4
2	6	7	4	5
3	13	6	12	5
4	14	3	5	5

Source: Fieldwork 1969.

Table 6.11 Seed Quality and Perception of Frost Damage

	Very Good	Good	Fair	Poor
1	3	6	1	1
2	4	9	2	7
3	6	8	8	14
4	7	8	3	9

Source: Fieldwork 1969.

Table 6.12 Fertiliser Use and Perception of Frost Damage

	Never	Occasionally	Regularly
1	0	4	7
2	3	6	13
3	6	12	18
4	6	9	12

Source: Fieldwork 1969.

Table 6.13 Memory of Frosts 1968 and Perception of Frost Damage

	Very Good	Good	Fair	Poor
1	3	6	1	1
2	4	9	2	7
3	6	8	8	14
4	7	8	3	9

Source: Fieldwork 1969.

the area was in the 1940s. The best relationships with perceptiveness were with those variables that are primarily economic in nature. For example, increasing degrees of perceptiveness are especially strongly associated with farm size and cultivated acreages. The better perceivers tend to be in the larger size categories (Tables 6.6 and 6.7). The better perceivers also tend to concentrate more on livestock, whilst most of the cereal farmers are found in the lower categories (Table 6.8). The two cereal farmers rated amongst the best perceivers were both in the second largest category for cultivated acreage farmed, one of them specialising in the production of oats for seed. The other cereal

farmer in the best perceivers category did not have any livestock.

Perceptiveness of frost damage is also associated with non-agricultural employment. With one exception, category one perceivers do not have non-agricultural employment (Table 6.9). The exception teaches school in Lac La Biche and is a relatively young and extremely ambitious farmer, primarily concerned with building up his farm. The most perceptive farmers also visit their district agriculturalist more often than other groups, use higher quality seed and use fertiliser to a greater extent (Tables 6.10 to 6.12). Of the four farmers in the first perception category who use fertiliser 'occasionally', two of them are primarily concerned with livestock and two are 'mixed farmers'. From these tabulations it is clear that those farmers who perceive frost damage most accurately are economically among the most successful, and therefore best adapted to the physical environment. Furthermore, the better perceivers have found less need to obtain an alternative source of income, another indication of their greater farming success. On the other hand it may be noted that economic success (indicated here by size of cultivated farm, type of farming, and fertiliser use) is not necessarily equated with perceptiveness, and that there are farmers with little knowledge of frost damage who are agriculturally successful. The chances of success are, however, considerably increased by a better than average perception of frost damage, one of the principal limitations to agricultural development in the area.

Perception of frost damage did not seem in any way related to experience with the frost hazard. 'Experience' was indicated by years farming within the area and age of operator. Most farmers contained within the sample had been farming within the area for longer than ten years. Even for relative newcomers the severity of frost damage in the last two years provided a considerable degree of 'experience'. There was a relationship between perceptiveness and memory, the better perceivers generally having better memories (Table 6.13). 'Memory' was classified according to the farmer's ability to remember specific dates of frost damage in 1968, and specific years notable for frost damage. Eight of the 11 perceivers in the first category considered the first fall frost most likely to occur in August, whilst only ten of the 21 who answered in the fourth category thought an August date most likely.

In terms of the relative resistance to frost of the three cereal crops under consideration, 65.7% of the perceivers agreed that wheat is the <u>strongest</u> in the spring, whilst 24% thought oats the stronger of the other two. The most frequent order of resistance recorded was wheat, oats and barley, the most common disagreement being in the relative ranking of wheat and oats which has already been noted. Wheat was placed only four times in the lowest resistance category and barley was considered stronger than wheat and oats only by perceivers in the lowest two categories. Just 12 members of the sample reported that the relative ranking of crops in their resistance to frost varied according to the stage of growth.

Perception of the Frost Hazard

Of the sample 40% considered frost the most important physical hazard, 28% drought, 20% frost and drought, whilst just 2% thought hail to be the most significant hazard. Drought was considered to be a greater limitation than frost only in the Iron River sample area. Farmers who stated drought as the greatest physical limitation to farming in the area generally emphasized mal-distribution of precipitation and not total moisture deficiency. It is probable that adequacy of spring moisture is uppermost in farmers' minds at seeding time although, in fact, it is the frost-free season that is a much more stringent determinant of the start and sequency of sowing times. However, for nearly three-quarters of the sample, frost, on its own, or in conjunction with some other natural hazard, was considered to be the most important physical hazard. For the greater part of the sample, frost occurrence and frost damage are accepted as an integral part of farming within this area and, as such, the frost hazard constitutes an insignificant part of farmers' 'mazeways'. Thus, for example, farmers can only in general remember details of frost occurrence for the previous season. Not one farmer in the sample kept any record of frost damage or the frost-free season. Because of this sub-conscious acceptance of frost, farmers do not perceive any adjustments of a practical nature at all. When asked what measures (for example, crop types and varieties, land use allocation, summer fallowing, fertiliser) were undertaken to reduce the risk of frost damage the initial answer in virtually all cases was 'Nothing', or 'what can you do about frost'. A representative comment to illustrate farmers' feelings would be "if it's gonna freeze, it's gonna freeze". Frost is realised as an unpredictable hazard

against which there is no defence. Farmers do not primarily consider their choice of farming practice, crop varieties or fertiliser with respect to the frost hazard. Traditional practice, hopeful economic return and yield potential are the basic factors behind the decision-making process.

Once the major decisions have been formulated for the next crop season, adjustments, which reduce the frost hazard as far as possible, are automatically made. However if the frost hazard is to be substantially reduced then it will be necessary to elevate the problems posed by frost into one of the major factors of farmers' decision-making processes. It is because farmers do not fully perceive the implications of the short frost-free season, that there is a lack of total adjustment to the frost hazard. Failure to eliminate the hazard is partly the result of the fact that farmers do not think they can do anything about frost. It is only after decisions have been made that some concession is made to frost. For example, wheat is grown on higher land and seeded first, and barley is sown later on the lower land. Unfortunately this does not eliminate the frost hazard, but merely brings to equality the frost risk for both crops. If a very quick growing barley variety is grown, it is often because it is sown so late that a short season crop has to be seeded. The increasing importance of rape within the area is primarily because rape is a cash crop in demand, and not because it is a relatively short season crop. Indeed rape is frequently sown on the lower land. Fertilisers are evaluated mainly as a means of increasing yields. Frost, a neglegible element in farmers' mazeways, does not have an important role in the decision-making process. Agricultural practices are not geared

primarily to the climatological base. As a result the ramifications of the frost hazard are not understood. Farmers do not associate moisture deficiencies with the short growing season.

Undoubtedly the major concerns of farmers in this area are prices and decreasing economic returns. When asked whether the Government should pay compensation for frost damage, the most frequent answer was 'no' but that the Government should do something about prices.

An important suggestion comes out of this discussion. If farming is to be adjusted to the environment, then farmers must be made aware of all the implications of the frost hazard. Also farmers ought to realise that the optimal adjustment to the physical environment does give the best chances of long term economic success. As long as farmers feel there is still a market for wheat, wheat will be grown irrespective of the climatic hazard. At the moment, significant alterations in farming practices resulting in a better adjusted farming economy will only occur through economic pressures. Adjustment in this manner is slow because of human inertia, inability to finance change, built in subsidies and price controls, and because demand for many agricultural products is cyclic. An alternative would be to increase farmers' perception of the frost hazard. Adjustments in the farming community are generally left to the individual and adjustments required to counteract the frost hazard are no exception. Total and successful adjustment is not likely to occur unless the problem is perceived fully first. It seems necessary therefore, to increase farmers' awareness of the frost hazard through all the usual information channels (e.g., farming journals, T.V., radio and visits by the district agriculturalists). This would provide a less painful way of

adjusting than that caused only by economic pressures.

Comparision with other Natural Hazard Perception Studies

This study has not really confirmed or denied previous findings in natural hazard perception. However such a hazard as frost has not really been dealt with previously. The threat of frost is one of constant limitation rather than a sudden and dramatic geophysical event. It is probably because frost is always there that farmers accept it in the manner they do. This was reflected in the surprise that many farmers showed at somebody wanting to ask questions on frost. There are perhaps other reasons for the failure of this chapter to verify previous results. There is not a regional variation in the frost hazard so there was very little chance of obtaining a spatial component to farmers' perceptions of various aspects of the frost hazard. Also because of a lack of records it is not really possible to test whether farmers underestimate the frequency of frost damage or not. However even if patterns, spatial or otherwise, in the perceptive processes are not elucidated, it is always important and beneficial to relate any problem to the manner in which the people who are concerned perceive it.

CONCLUSION

Although detailed conclusions have been given for each chapter where appropriate, it may be beneficial to summarise the major points.

1. There are no important regional differences in the frost hazard within northeast Alberta. On the contrary micro-variations in minimum temperature distribution, for example between plateau top and small valley floor, are significant.

2. Because of micro-climatic factors affecting the sites of meteorological stations, the sharp changes in minimum temperature distribution, and because of climatic cycles it is difficult to suggest a 'representative' frost-free period for northeast Alberta. Analysis from the temperature traverse results in association with a study of the 1959-68 period suggest that a period of no more than 85 frost-free days would be most appropriate. If Longley is correct in thinking that the 1951-64 warm period has ended, and the shortness of the frost-free seasons since 1964 suggests this, then even an 85 day frost-free isoline enclosing the area as a whole may be too optimistic.

3. Within northeast Alberta because of the pronounced misrepresentation of some of the stations' minimum temperature records, because of the decrease in temperature from screen to ground level with normal temperature distribution at night, and because of spatial variations in frost risk, a screen temperature of $32^{o}F$ does

provide the critical limits of the frost-free season.

4. The frost hazard is an important physical limitation in reducing the chances of farmers in northeast Alberta obtaining an income comparable with the provincial average. The short and variable frost-free season prevents the sustained, high quality production, on a large scale, of the basic crop of Prairie agriculture, wheat. The sporadic occurrence of summer frosts is also a threat to short season crops grown on the most favourable land in some years. Even livestock operations suffer a comparative, regional disadvantage as a result of the short growing season. However, the disadvantage in the latter case is less than in the production of cereal crops, especially wheat. Mixed farmers are able to obtain high cash returns for their cash crops in the 'good' years and are still able to find an outlet for their crops (i.e. as livestock feed) in the 'bad' years.

5. The frost hazard ultimately depends upon the decisions made by farmers. The agricultural response to the short growing season is sub-optimal with the widespread production of wheat being the greatest single maladjustment to the physical environment. The frost hazard could also be considerably reduced by a more careful selection of crop varieties, use of better quality seed and a more constant and widespread application of the appropriate fertilisers at a suitable time during the growing season.

6. This lack of adjustment results partly from political pressures in the past to grow wheat, and partly because of farmers' perception of the frost hazard which places frost as an 'act of God' against which little can be done. Hazard reducing practices

as indicated above are not perceived as such. However, those farmers with a better awareness of the nature of frost damage tend also to be the most successful farmers in the sample.

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APPENDIX A

QUESTIONNAIRE

Description of site of farm ______________________________

General Information

1. How long have you been farming here? ______________________
2. Have you ever farmed elsewhere? ______________________
3. If so, where? ______________________________
4. What is the total size of your farm? ______________________
5. What were your acreages of crops in 1968?

   Wheat ____________ Barley ________ Oats ____________

   Summer fallow ________ Grasses ________ Pasture __________

   Rape ______________ Flax ________
6. What were your livestock totals in 1968?

   Pigs __________ Milk cattle __________ Beef cattle ________

   Poultry ________ Sheep ______________ Horses __________
7. What age group do you fall in ?

   15-19 ________ 20-24 ________ 25-34 ________ 35-44 ______

   45-54 ________ 55-64 ________ 65 plus __________
8. What level of formal education did you receive?

   None ____________ Elementary ________ High School __________

   University ____________ Agricultural College ____________
9. Where were you born? ______________________________
10. Where did your parents come from? ______________________
11. Do you have any other form of employment ? ________________
12. If yes, what? ______________________________
13. Is this job seasonal?

    Full time ________ Winter ________ Summer __________

14. What percentage of your income comes from this on average? ______

15. What kind of seed do you use? ______

16. How often do you change your seed? ______

17. Where do you obtain your seed from? ______

18. Do you take Publication 91, "Varieties of Grain for Alberta?" ______

19. How many times a year do you see your district agriculturist? ______

20. Which farming journals do you take?
    i) ______ ii) ______
    iii) ______ iv) ______
    v) ______

21. Do you use fertiliser?
    Regularly ______ Occasionally ______ Never ______

<u>Perception of the Frost Hazard</u>

22. How much of your crop did not get harvested in 1968?
    Wheat ______ Barley ______
    Oats ______ Rape ______
    Flax ______

23. What were the reasons? ______

24. What date did you start to harvest in 1967 and 1968? ______

25. What date did you complete your harvest in 1967 and 1968? ______

26. How often do you expect your crops to be damaged by frost in 10 years? ______

27. What years in the last 10 have been bad for frost?
    ______ ______ ______ ______

28. Does frost occurrence vary within your farm? ______

29. If 'yes' where are the most frost-prone areas? ______

30. What date did the last spring frost occur last year ? ______

31. Have you ever reseeded because of a spring frost? ______________

32. What date did the first fall frost occur last year? ______________

33. What date do you expect the first fall frost? ______________

34. Whic is worst, a spring or a fall frost? ______________

35. Do you believe that excessive May rainfall will result in a June free of frost? ______________

36. At what temperature does frost damage
    i) Wheat? ______________
    ii) Oats ? ______________
    iii) Barley? ______________

37. In what order of resistance to frost would you place these crops?

Spring	Fall
1. ______________	1. ______________
2. ______________	2. ______________
3. ______________	3. ______________

38. How long is the growing season usually? ______________

39. By how many days does the growing season vary from year to year?
____

40. With what weather conditions do you associate frost?
    i) ______________ ii) ______________
    iii) ______________ iv) ______________
    v) ______________

41. Did yields differ in each of the years 1966, 67, 68? ______________

42. If 'yes', why? ______________

43. Have you ever tried growing winter wheat ? ______________

44. If 'yes', why? ______________

45. If 'no', why? ______________

46. Do you regard frost as the major physical hazard? ______________

47. If not, what is your main physical hazard? ______________

48. Do you sow your crops at the same time every year? ______________

49. If, 'yes', when?

Wheat ______________ Oats ______________

Barley ______________ Rape ______________

50. Why? ______________

51. If not, why not? ______________

Adjustment to Frost Hazard

52. What methods do you use to reduce the frost risk?

i) Fast maturing varieties ______________

ii) Fertilisers ______________

iii)Diversification ______________

iv) Rational land use planning ______________

v) Insurance ______________

vi) Others ______________

53. Why do you use fertiliser?

1. ______________

2. ______________

3. ______________

54. Do you insure your crops? ______________

55. What crop types do you use?

1. Wheat ______________ 2. Oats ______________

3. Barley ______________ 4. Rape ______________

56. How many years of consecutive crop failure could you withstand?

____

57. Should the Government pay compensation for a frost damaged crop?

____

58. Why do you farm? ______________

59. Estimate your yield and grade losses due to frost in 1968.

	Expected yield and grade	Actual yield and grade
Wheat		
Oats		
Barley		
Rape		

60. Estimate the effects of this year's June frosts.

____

APPENDIX B

Meanook Sample Area

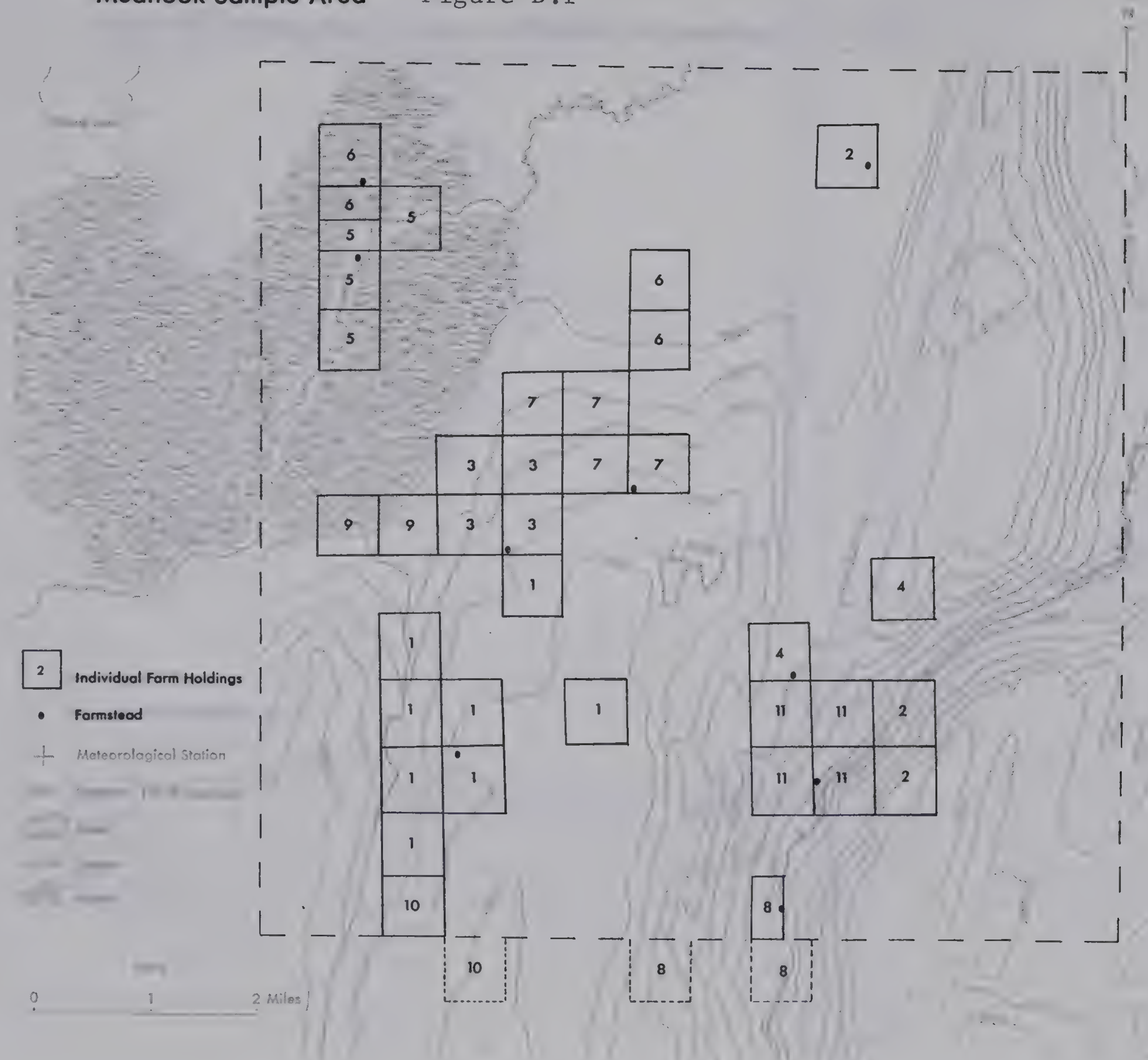
This area is situated within Athabasca County, its coordinates being NW 1/4 33/65/23; SW 1/4 33/64/23; NE 1/4 33/65/22; and SE 1/4 33/64/22 west of the 4th meridian. The site of the meteorological station in relation to topographic features and the distribution of sampled farm holdings and farmsteads is illustrated by Figure B.1. The topography consists basically of an undulating plateau which has been deeply dissected in the southeast by the Tawatinaw River and indented in the west by the very small Price Creek. The plateau level loses height towards the northwest, where an extensive area of marsh was shown on the 1951 survey. The Meanook station is sited on the highest land within the sample area, with the exception of a small area along the southern boundary. This point is clearly illustrated by the configuration of the contours in Figure B.1. The station in fact is situated on the top of a prominent knoll that rises steeply above the surrounding plateau surface. It should be expected, then, that from the standpoint of minimum temperatures, the temperature records of this station would be extremely favourable, and most unrepresentative of the remainder of the sample area.

The records of the last ten years certainly give a charitable impression of the frost-free season for such an area (Table B.1). In the last ten years Meanook has not recorded a frost-free season less than 106 days (1959) nor a single frost occurrence in June, July or

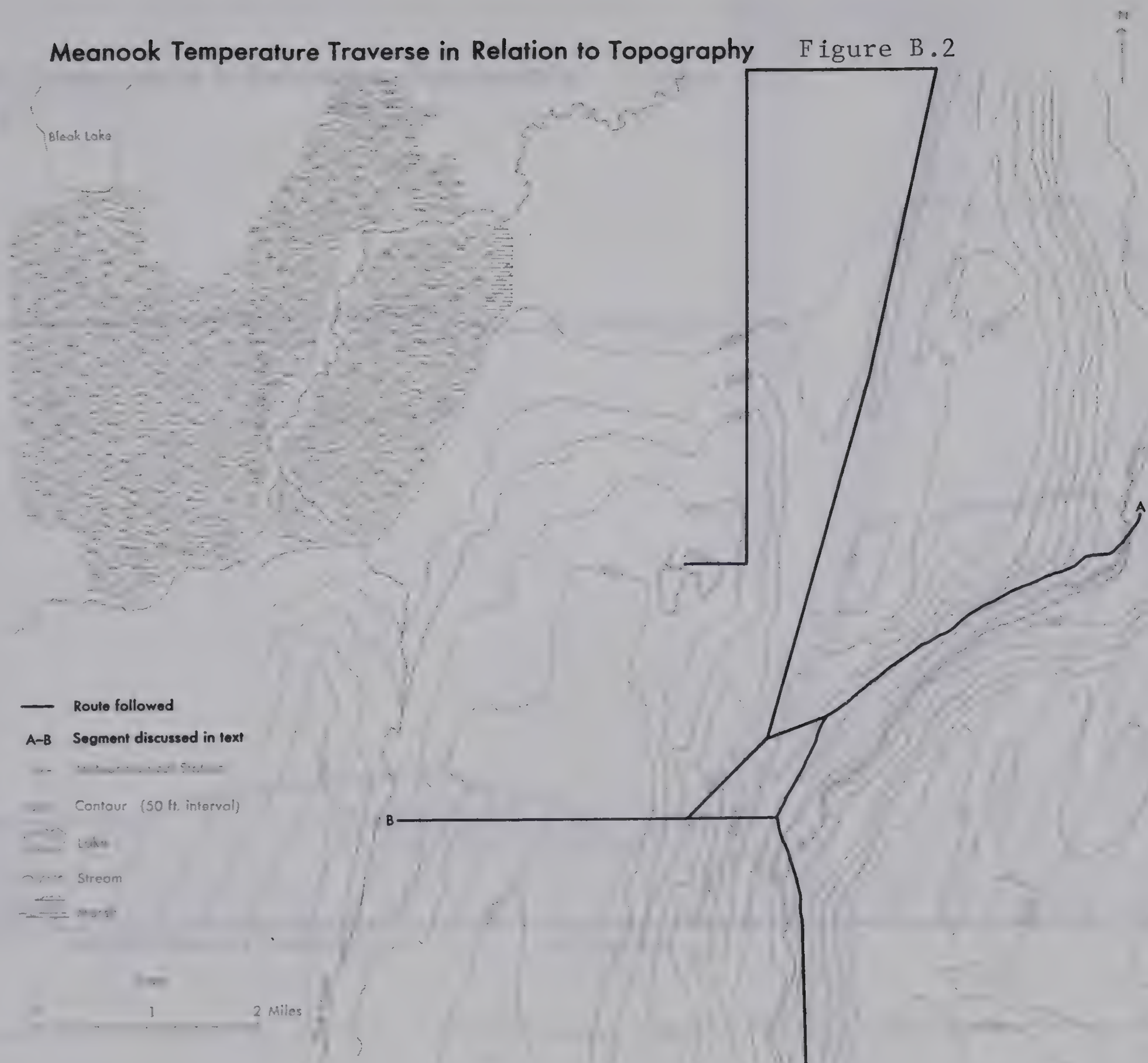
August. On the contrary, on three occasions frost-free seasons of over 140 days have been registered (1960, 1966 and 1967) and the first fall frost has not occurred till October on three out of the ten years under study. On the basis of the records of these last ten years there is no risk of frost in spring after June 1 or before August 31 in the fall. On May 15 the risk of spring frost is 50% and this decreases to 10% by May 25. In the fall the probability of frost having occurred on or before September 10 is 50%. As regards killing frosts there is only a 10% risk of frost after May 15 in the spring, and a 20% risk by September 10 in the fall. To provide a deeper insight into these records, a temperature traverse was conducted on October 3 around sunrise under calm and clear conditions. Because of access problems the route selected for the traverse omitted the northwest corner of the sample area (Fig. B.2). To illustrate spatial changes in minimum temperatures a cross-section relating temperature change to topography was chosen from the traverse results, and a map showing the distribution of minimum temperatures over the entire route was also drawn. The temperature recorded by the station at the start of the traverse was 27.5°F (-2.5°C) and at the end 26.6°F (-3.0°C) so that adjustment was not deemed necessary.

The temperature-topography profile (Fig. B.3) illustrates the temperature change from the valley floor of the Tawatinaw River, across the Plateau surface to the small stream of Price Creek (segment A-B on Fig. B.2). This profile reveals two marked temperature inversions. It will be noted that the inversion along Price Creek is greater than that in the much more deeply incised Tawatinaw. This is due to the extensive tree cover in the valley of the Tawatinaw which provides some degree of protection from cold air drainage. The inversion in the

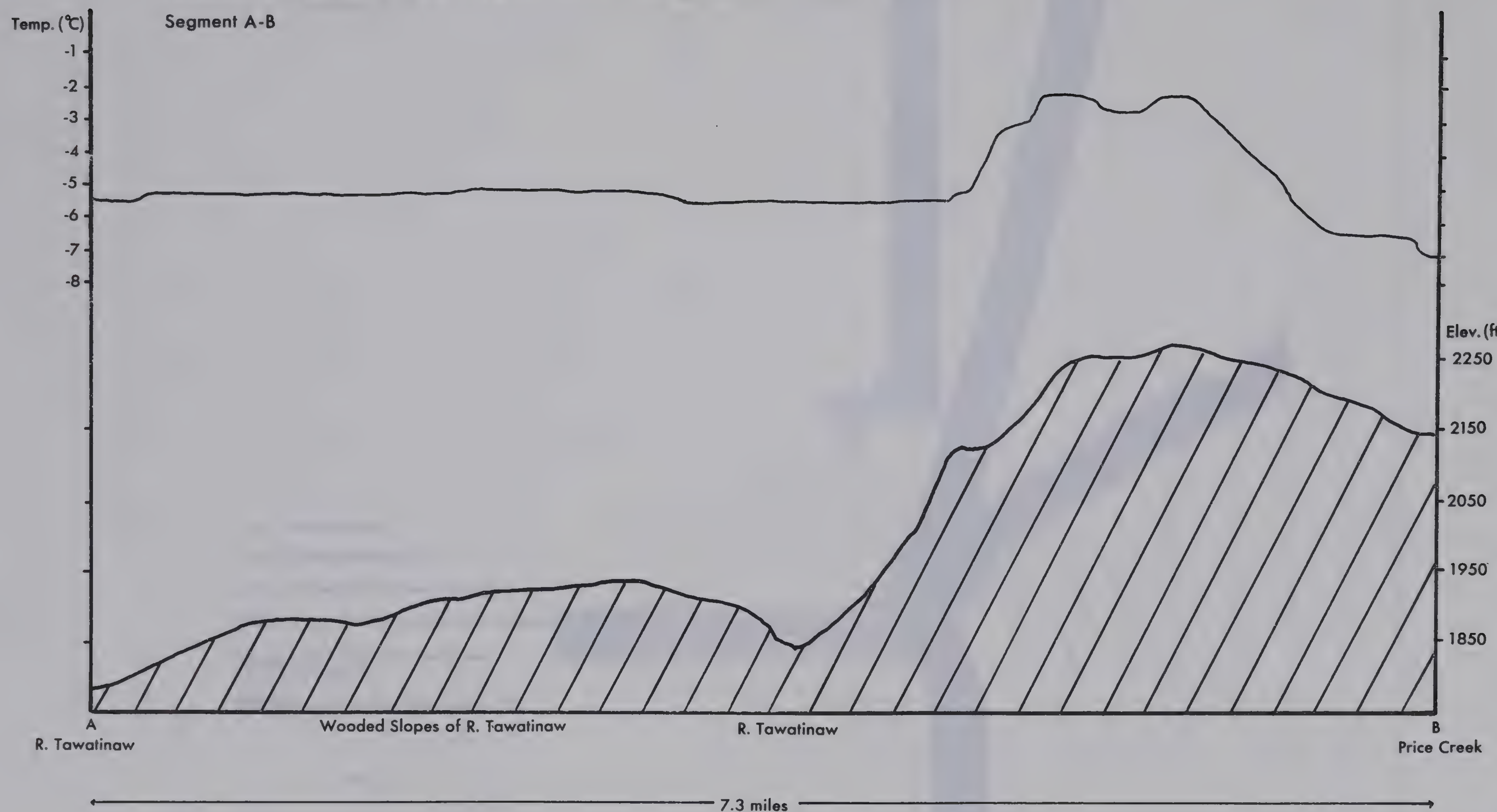
Meanook Sample Area Figure B.1

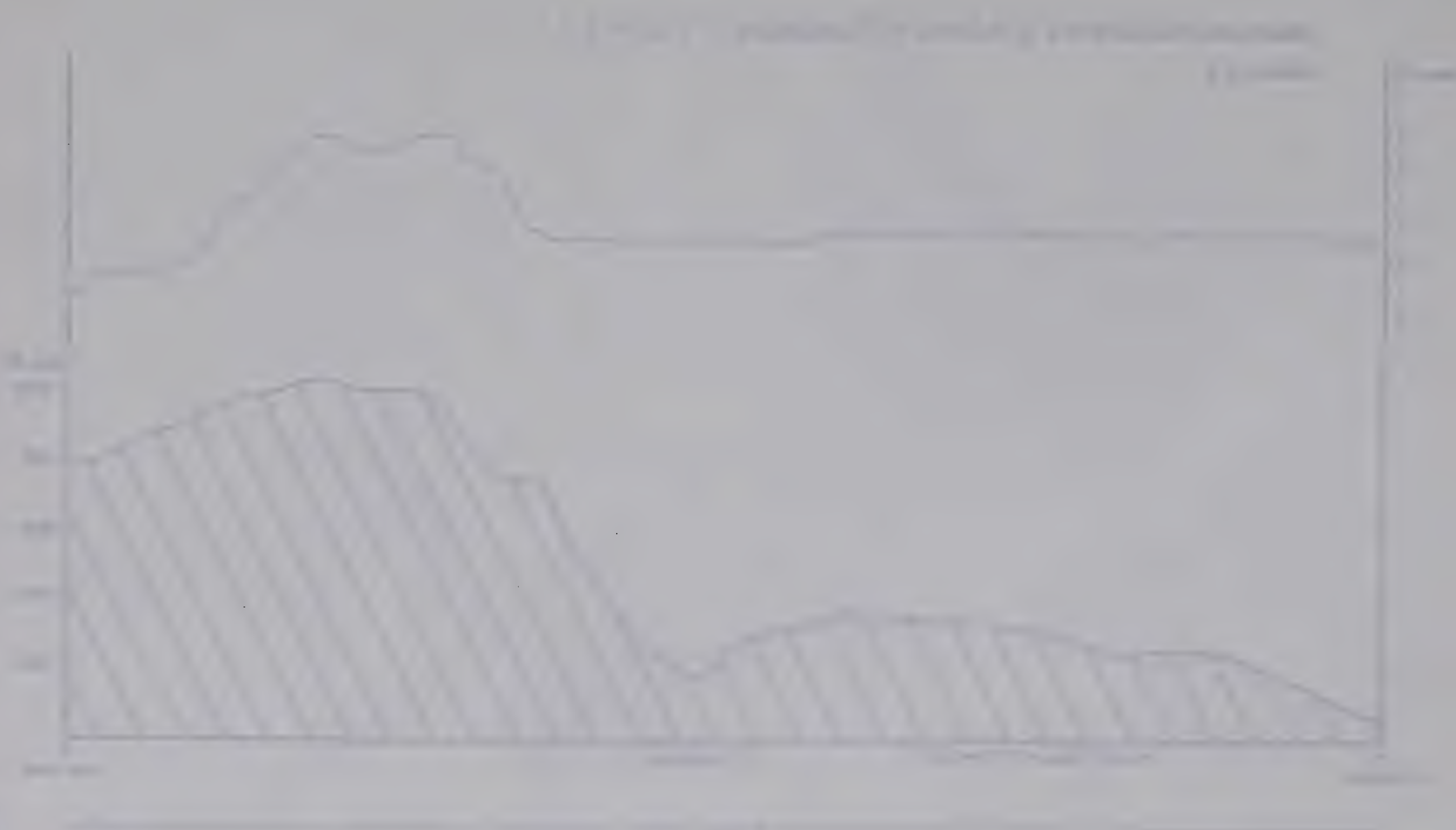


Meanook Temperature Traverse in Relation to Topography   Figure B.2



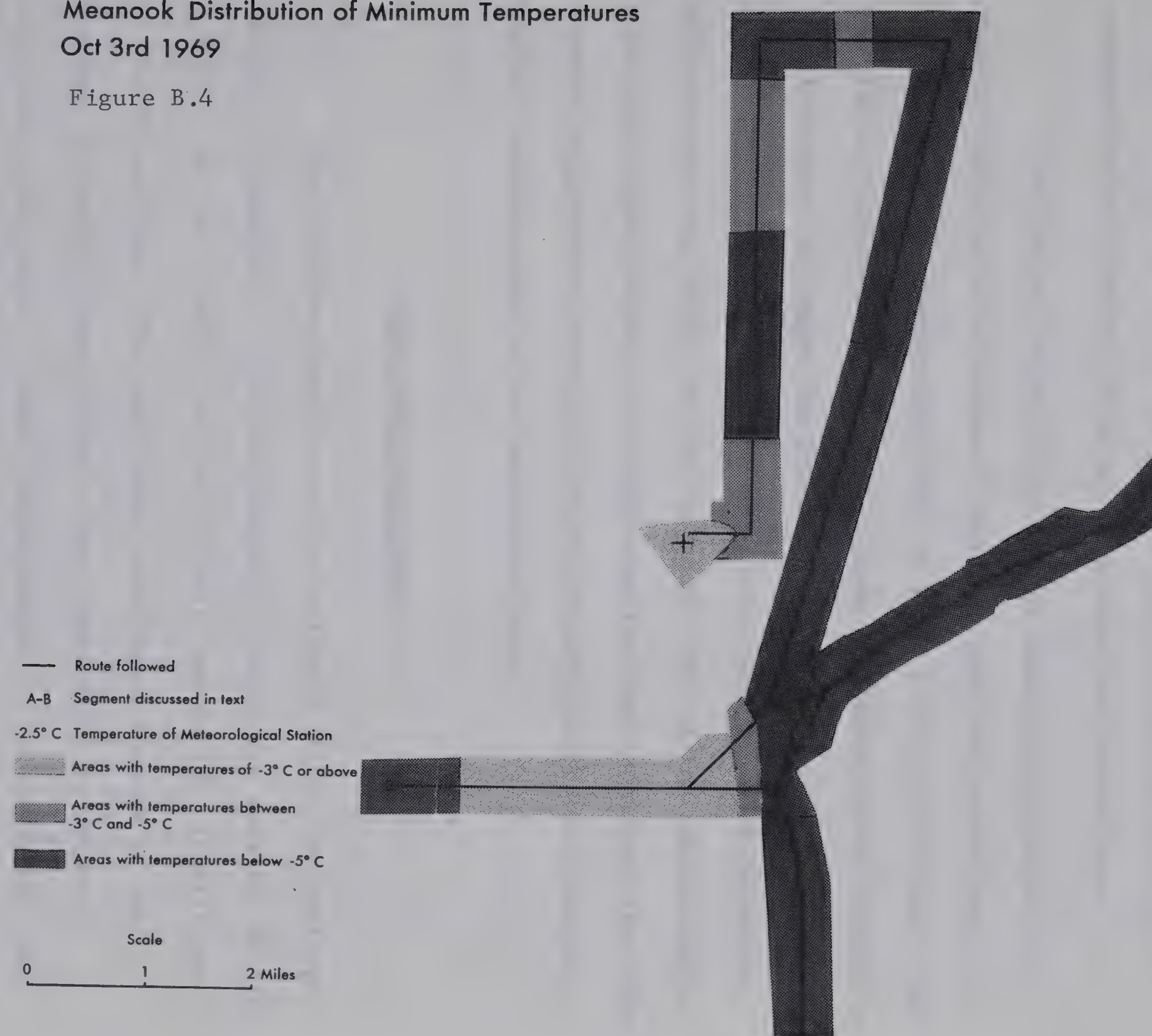
Meanook; Temperature in Relation to Topography   Figure B.3





Meanook Distribution of Minimum Temperatures
Oct 3rd 1969

Figure B.4



Tawatinaw valley amounts to 3.0°C (5.4°F) and the inversion along the Price Creek is 4.6°C (8.1°F). Figure B.3 also indicates the only locality over the entire route with a temperature similar to that recorded by the station. This is, of course, the plateau top.

The spatial extent of areas with temperatures similar to those of the station is extremely limited. Over the greater part of the traverse route temperatures were at least 2.5°C (4.5°F) lower than the station temperature (Fig. B.4). Areas with temperatures similar to the station are all above the 2225' contour and areas with temperatures at least 4.5°F below the station temperature are generally below the 2175 contour (Fig. B.2). By far the larger part of the sample area is below this latter contour. The cross-sections and maps drawn from this traverse suggest most strongly that the Meanook temperature records are not representative of the surrounding area.

Cold Lake Sample Area

The Cold Lake sample area lies entirely within the Municipal District of Bonnyville. The coordinates of the sample area are NW 1/4 21/63/2; SW 1/4 21/62/2; SE 1/4 21/62/1; and NW 1/4 21/63/1 west of the 4th meridian. The coordinates were chosen because of the presence of the Cold Lake Air Force Base immediately to the west, Cold Lake to the north, a large Indian Reserve to the southwest, and the termination of agricultural land-holdings to the east. The location of the meteorological station, the sampled farmsteads and their individual holdings with respect to topographical features are shown on Figure B.5. The area is essentially a low lying plain below 1775' bounded by a high ridge in the southeast, and in the north by Cold Lake.

Although the relief shows a tendency to 'dip' towards the centre of the sample area, in detail the surface is characterised by several steep-sided ridges and long shallow hollows. Marsh occurs frequently around the shores of Cold Lake, whilst poor shrub and muskeg are distributed especially on the eastern margins of the sample area. The remainder of the area is open farmland. The meteorological station is located within the Cold Lake Air Force Base on level ground, in the vicinity of aircraft hangars. As such there appear to be no significant micro-climatic factors affecting the temperature readings of this station.

Next to Meanook, the records indicate that Cold Lake enjoys the longest frost-free season within the study area with frost-free periods of 156 days (1960) and 151 days (1966) being recorded (Table B.2). The shortest seasons occurred in 1967 (92 days) and 1968 (93 days), with frost occurring on July 1 in 1968, the only record of a July/August frost in the last ten years. The percentage risk of a spring frost occurring after May 15 is 60%, and 20% after May 31. There is no possibility of a fall frost before August 31 but there is an 80% probability by September 10. If 28^{o}F criterion is used there is a 30% chance of a spring frost after May 15 but no chance after June 1, and there is obviously no probability of a killing frost before August 31. By September 10 the risk of a killing frost is 40%. This area, like Athabasca, Iron River and Lac La Biche, is on the extreme margin of cultivation and the records suggest an extraordinarily long frost-free season for such a location.

A temperature traverse was undertaken around sunrise on October 12 when weather conditions were both clear and calm (Fig. B.6). Because of the eccentric location of the meteorological station, the

traverse started there but finished within the sample area. However, the meteorological observers at the base who are on 24 hour duty confirmed the uniformity of temperature at this base during the traverse period. The temperature recorded by the station was 22.7°F (-5.2°C) at the start and 22.0°F (-5.6°C) at the end of the traverse. It was not possible to start the traverse at the site of the meteorological station but 1/2 mile away, at the gate of the Air Base. The temperature recorded by the traverse was 21.2°F (-6.0°C) at this point and for the purposes of map drawing this will be the temperature used. Because this is 1.5°F below the temperature of the station, the results will serve only to emphasize the conclusions. The highest temperature recorded during the traverse was 21.2°F (-6.0°C) which occurred at the Air Base and alongside the waterfront at Cold Lake. At every other point along the route the temperature was below that recorded by the meteorological station (and by the temperature at the Air Base gate). Three temperature-topography cross-sections and a map of temperature distribution for the entire route were drawn from the traverse. Figure B.6 (segment A-B on Fig. B.6) is a west-east profile from the meteorological station due east to the limits of the sample area. This shows temperature inversions of 2.8°F (4.7°F) and 2.0°C (3.6°F), and even in the vicinity of a prominently high ridge, temperatures still do not reach the level recorded at the start of the traverse. Figure B.8 (segment C-D on Fig. B.6) likewise shows the inverse effect of relief, for example the valley of the Beaver River, and the moderating influence of large bodies of water which may counteract completely the effects of cold air drainage. Thus, although the relief drops noticeably towards Cold Lake, the effect of this large body of water is to increase

Cold Lake Sample Area Figure B.5

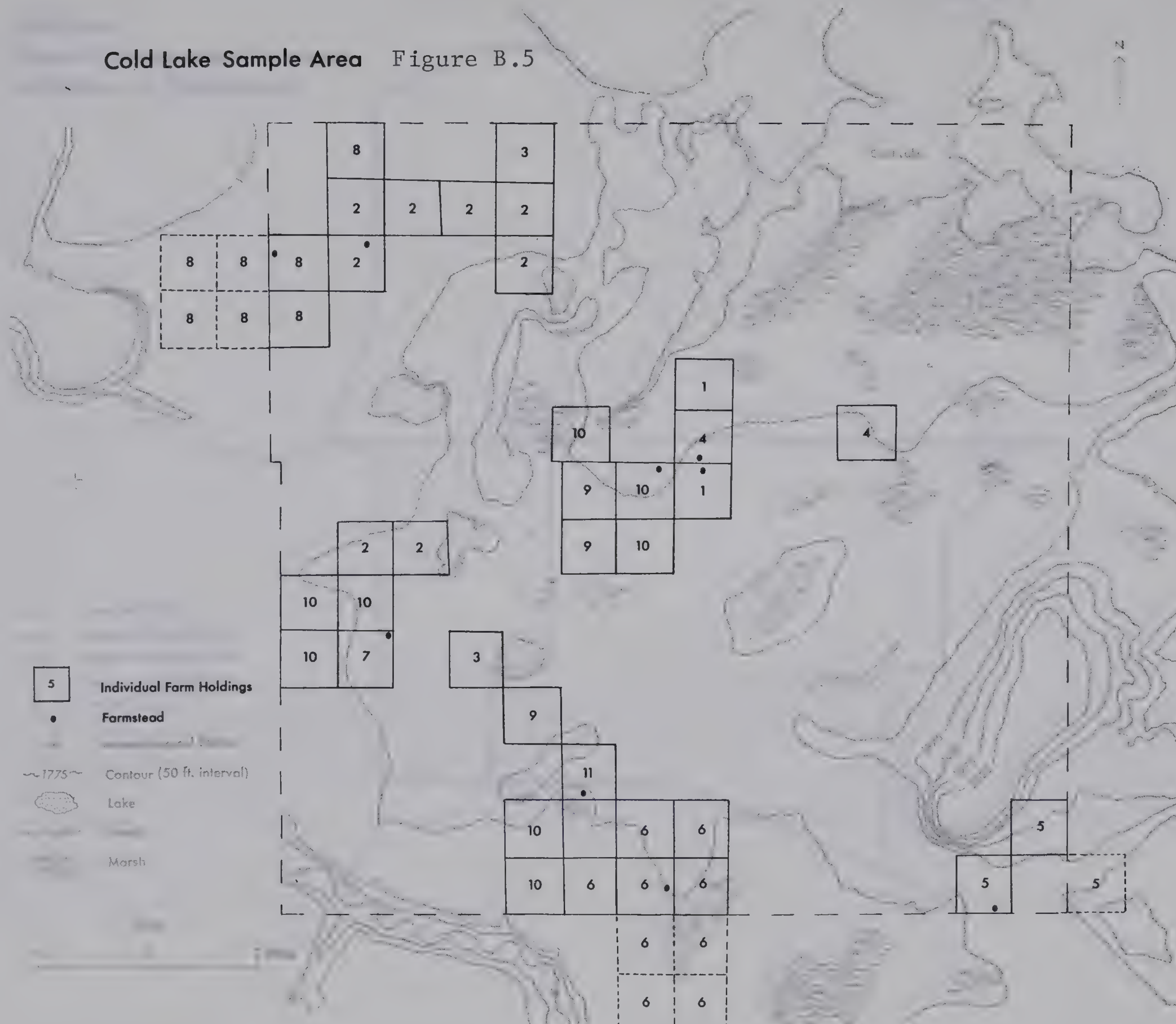


Figure B.6

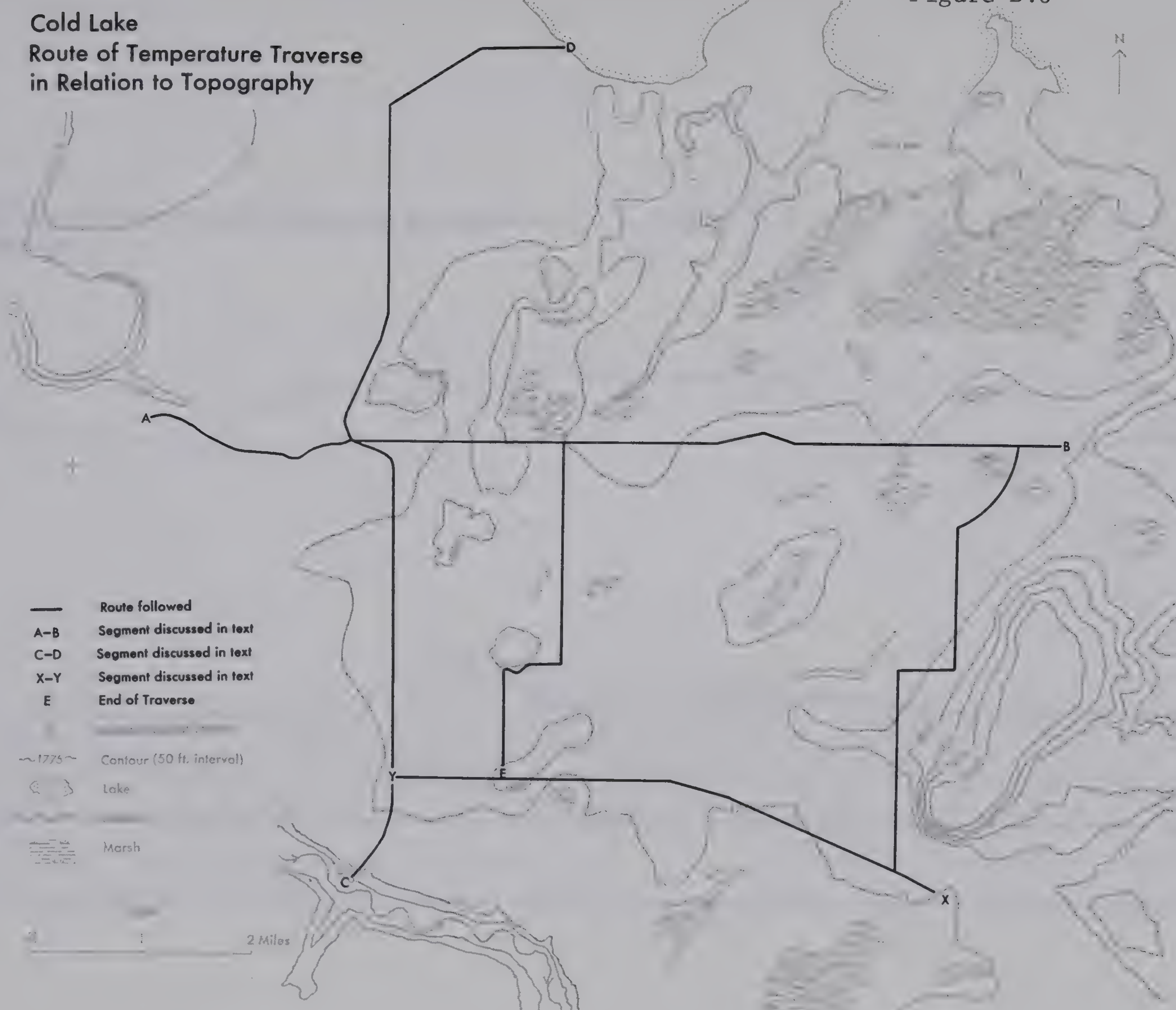
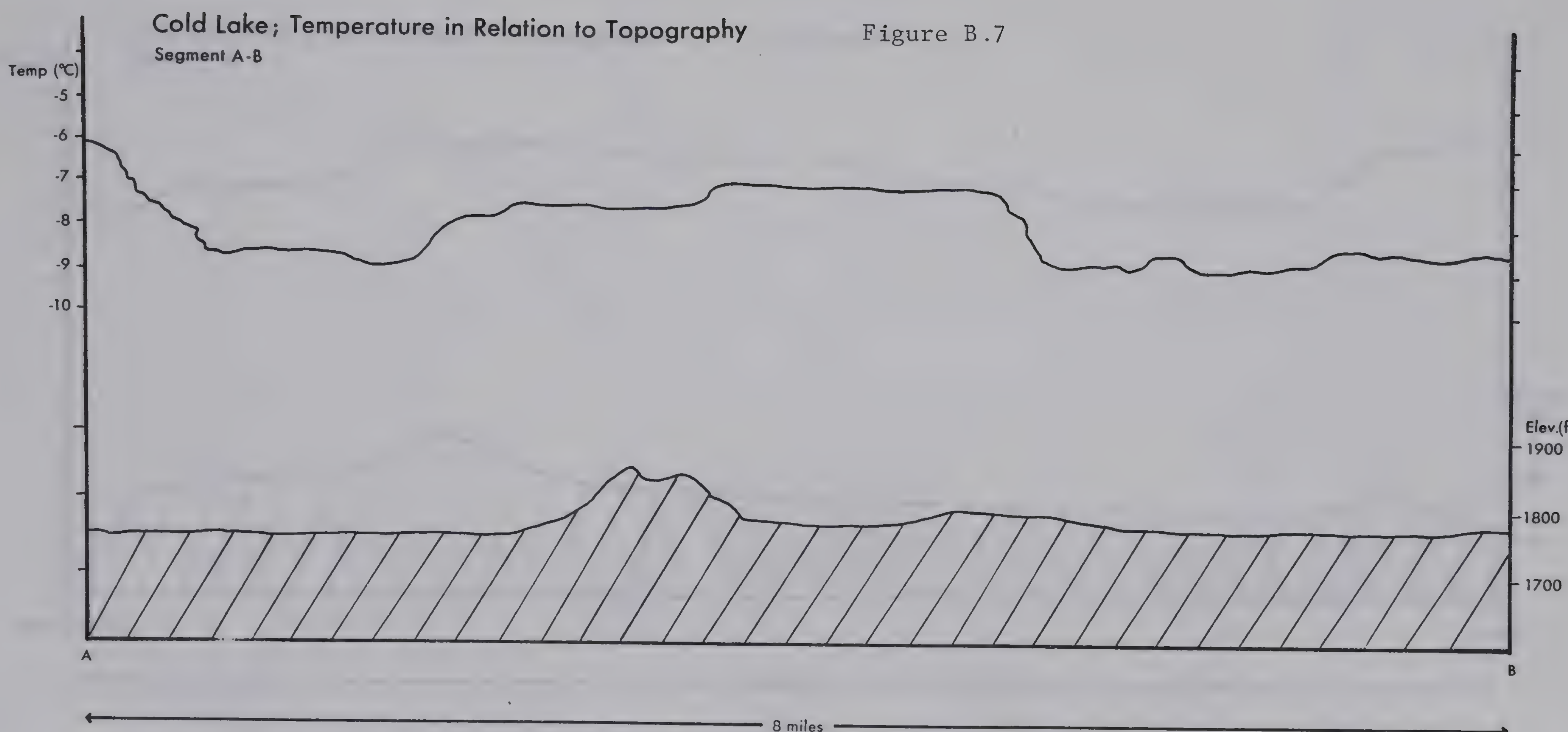

Cold Lake
Route of Temperature Traverse
in Relation to Topography
N
A
B
C
D
E
X
Y
Route followed
A–B Segment discussed in text
C–D Segment discussed in text
X–Y Segment discussed in text
E End of Traverse
1775 Contour (50 ft. interval)
Lake
Marsh
2 Miles

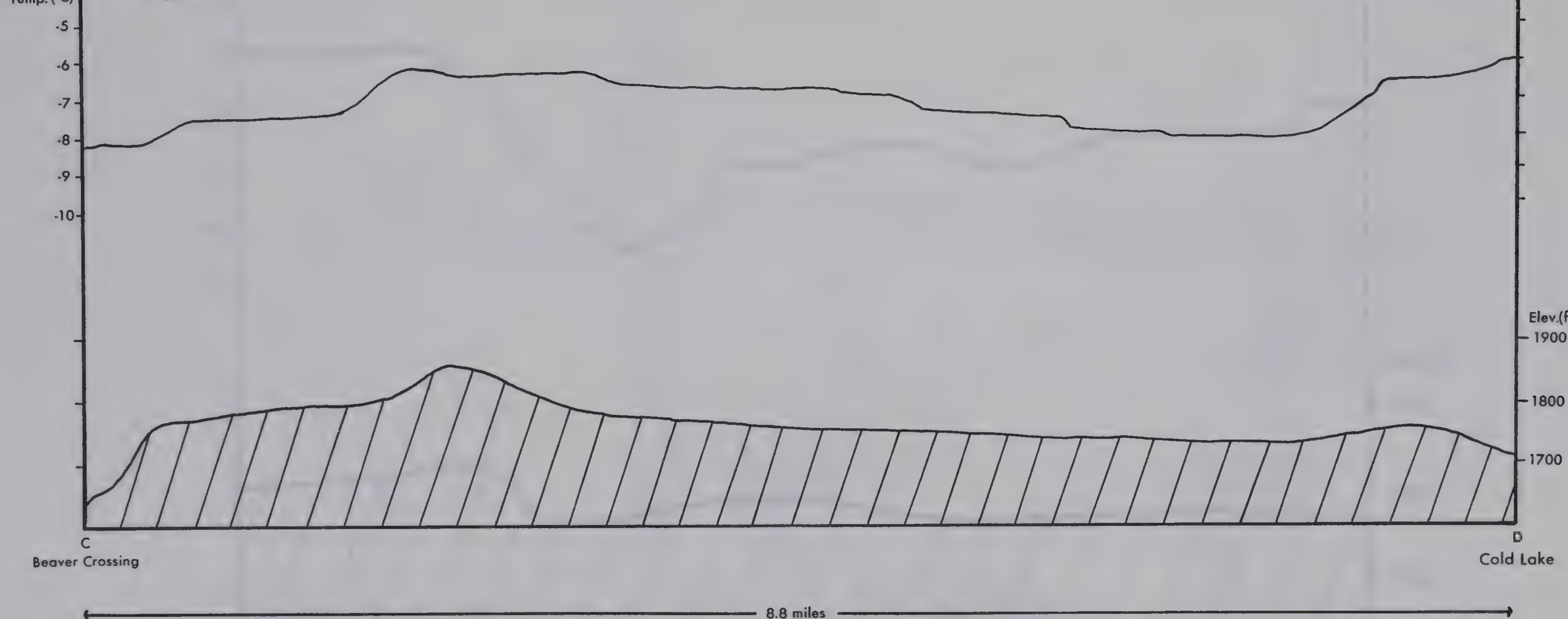
Figure B.7


Cold Lake; Temperature in Relation to Topography
Segment A-B
Temp (°C)
-5
-6
-7
-8
-9
-10
Elev.(ft)
1900
1800
1700
A
B
8 miles

Cold Lake; Temperature in Relation to Topography

Segment C-D

Figure B.8

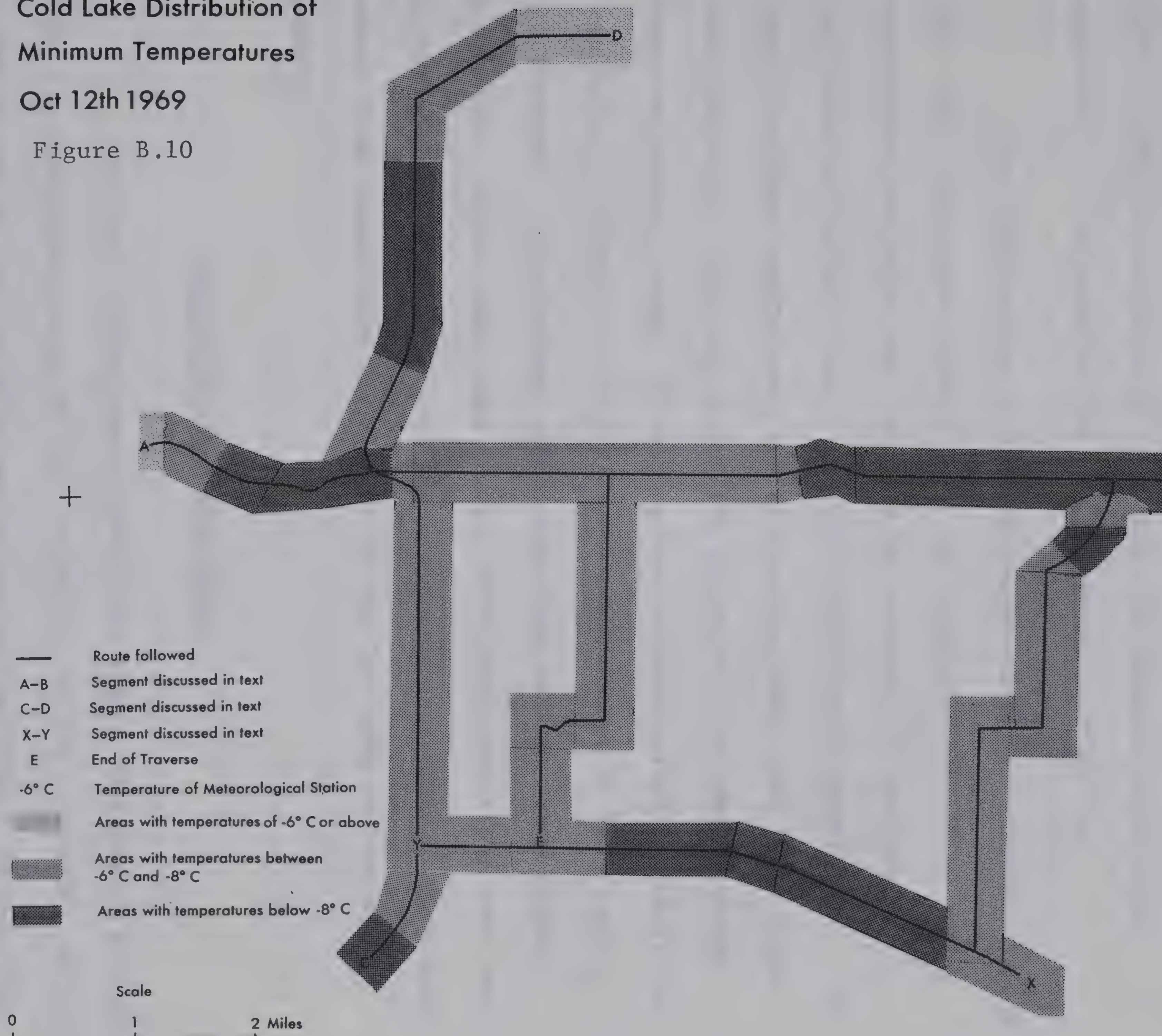


Cold Lake;Temperature in Relation to Topography

Figure B.9

Cold Lake Distribution of
Minimum Temperatures
Oct 12th 1969

Figure B.10



temperature by 2.0°C (3.6°F). Figure B.8 (segment X-Y on Fig. B.6) is an east-west profile and shows the largest inversion of the whole traverse, 3.5°C (6.3°F). Temperature also dropped by as much as 2.0°C (3.6°F) in the vicinity of muskeg, for example in the area immediately to the south of the 'B' coordinate on Fig. B.6.

The distribution of minimum temperatures over the whole route (Fig. B10) illustrates clearly that, for virtually the entire route, temperatures are below that recorded at the start of the traverse (and therefore an additional 1.5°F below the station temperature). In terms of minimum temperature, the station has been found to be representative only of the area around the shores of Cold Lake, although there are certain ridges, illustrated by the cross-profiles, where the temperature is within 1°C (1.8°F) of the temperature at the start of the traverse. It is perhaps unfortunate that many of these ridges are wooded. On the other hand, slopes both gentle and steep have been shown to cause substantial cold air drainage thus creating a much more severe frost hazard than the records of the Cold Lake station would suggest.

Lac La Biche Sample Area

The Lac La Biche sample area falls within Improvement District 102, its coordinates being NW 1/4 36/66/15; SW 1/4 36/66/15; NE 1/4 36/66/14; and SE 1/4 36/66/14 west of the 4th meridian. In this case the meteorological station is situated outside the sample area (Fig. B.11). The coordinates of the sample area were particularly difficult to determine due to the proximity of Lac La Biche, Missawe Lake, several large Indian Reserves, and the lack of a published land-ownership map.

The area finally chosen lies immediately to the south of the meteorological station, which is itself only 1/2 mile south of the lake shore, and immediately to the east of Missawe Lake. Considerable help was received from the local district agriculturalist (Mr. H. Yoder) in obtaining ownership maps and in the actual choice of the area. Further difficulties arose from the lack of topographic maps for the area, the only one being available on a 1:250,000 scale. Altimeter measurements were taken to provide extra spot height values but it was decided not to interpolate contours between those provided by the 1:250,000 topographic sheet, because of the complicated nature of the terrain. Figure B.10 shows the general height of the area to be around 1900' and whilst this gives a good indication of the general level of the area, the map omits many of the smaller scale relief changes. The altimeter measurements were useful in the drawing of the cross-profiles taken from the temperature traverse and verifying the true height of the meteorological station.

The height of the meteorological station (which is at Lac La Biche Airport) is given as 1875' on the 1:250,000 topographic sheet, 1859' in the official Department of Transport, Meteorological Report, and 1835' according to the instruments at the station itself. Altimeter readings taken by myself in the fall of 1969 would suggest 1835' to be the true height. The topographic sheet likewise found Missawe Lake to be at a height of 1875' and this was corrected to 1835' by altimeter measurements. The altimeter recordings, substantiated at the airport by their own instruments are taken as giving a more accurate assessment than the heights given by the topographic sheet. On the other hand the altimeter results tend to verify the 1900' contour of the topographic

sheet which is reproduced on Figure B. 11. The meteorological station is on a small knoll, overlooking Lac La Biche, and is well exposed except to the north where it is sheltered by a tree line. Proximity to the lake and situation upon a knoll would be expected to give higher minimum temperatures than might otherwise be expected.

Table B.3 indicates a marginal average frost-free period during 1959-68. Very short seasons were recorded in 1968 (60 days), 1965 (72 days) and 1967 (90 days). It will be noticed that all these years occurred after 1964. According to Mr. Ed. Higham, meteorological inspector for northern Alberta, the instrument shelter was much more heavily protected by trees and shrubs until 1964 than is the case now and he feels that this vegetation protection was quite significant in reducing heat loss at night (Pers. Comm., February, 1970). 1968 was the only year when a frost in July or August was recorded (August 13) and this was also the only year with a killing frost-free season of less than 100 days. On the basis of the 1959-68 data the probability of spring frosts after May 15 is 90% and June 1 is 40%. The chance of a fall frost before August 31 is 10% and by September 10 the chances are 60%. Probabilities using 28°F for the same dates are 30% and 10% in the spring and nil and 30% in the fall.

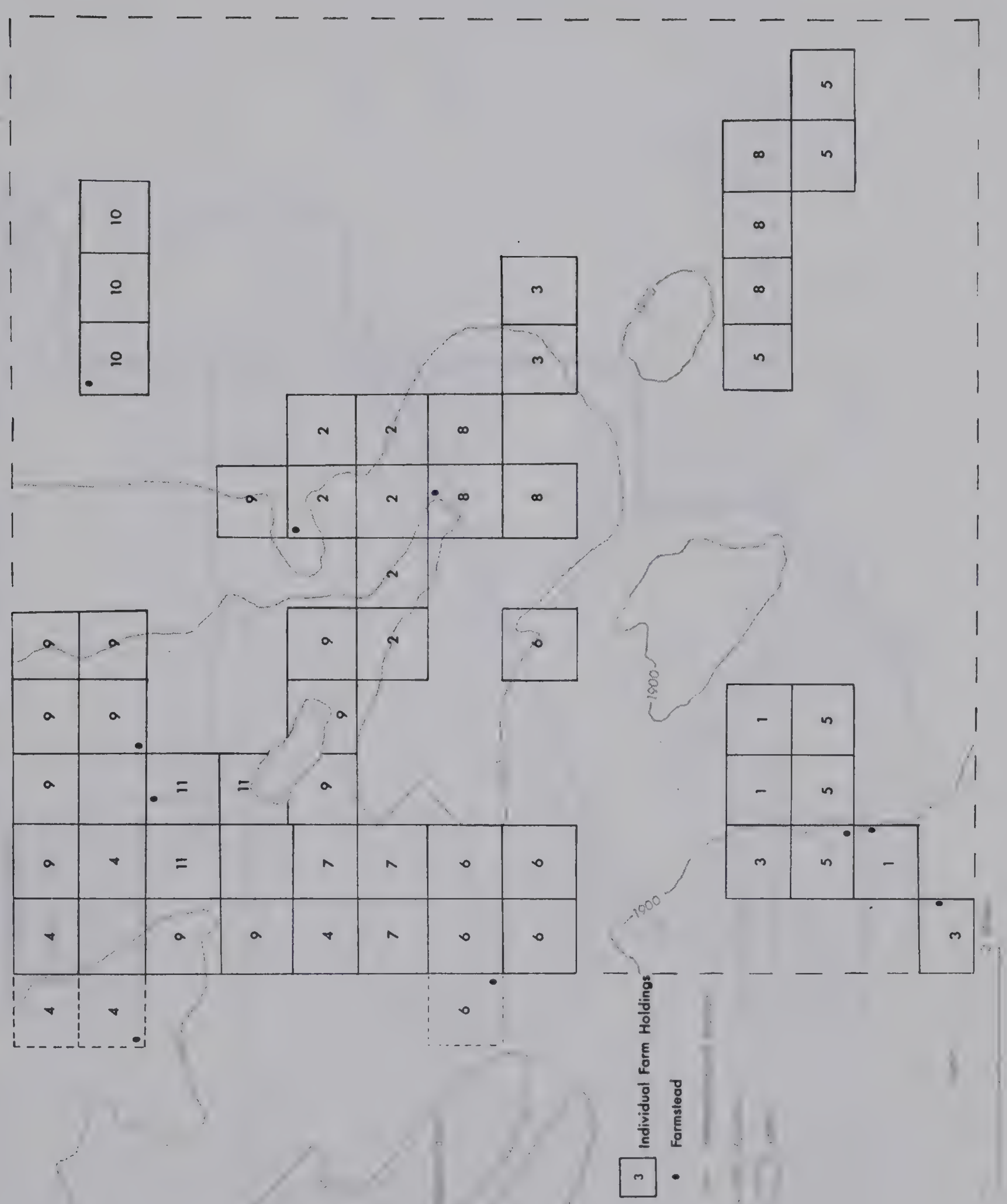
A temperature traverse was conducted on October 11, 1969, under calm, clear weather conditions and the route selected in relation to topography is illustrated in Figure B.12. The temperature of the station at the start of the traverse was 23.0°F (-5.0°C) and at the end 22.0°F (-5.5°C) so once again no adjustment was necessary. The highest temperature recorded was -4.0°C (24.8°F) and the lowest -8.8°C (16.2°F), giving a maximum variation of 4.8°C (8.6°F). Figure B.13

illustrates the temperature variations involved for a section of the route (segment A-B on Fig. B.12). Starting on high land approximately 1/2 mile from the station (and recording a similar temperature), the temperature gradually dropped as cold air drained into a shallow, undulating basin. The minimum temperature (16.2°F) was recorded in the vicinity of a dry creek. The temperature then rose as height increased until, at the top of a ridge over 1900' in height, the temperature recorded was almost the same as that recorded by the station. Despite a steady decline in relief, the temperature remained constant until in the vicinity of Missawe Lake, it increased to a maximum (24.8°F). This cross-profile illustrates the maximum variation in temperature registered by the traverse.

Figure B.14 illustrates the distribution of minimum temperatures along the route. The temperature beside the lake shore of Lac La Biche and that on the immediately surrounding higher land are the same as that recorded by the station. At only one other point along the route, in the vicinity of Missawe Lake, was the temperature greater than that recorded by the station. Nowhere else along the route did the temperature exceed the station's. For the most part temperatures were 1.1°C to 2.2°C (3-4°F) lower, and in certain hollows the difference was nearly 5.0°C (9.0°F). The study area is characterised by a series of sharp ridges and long shallow hollows and there is obviously a considerable amount of cold air drainage except in the vicinity of Lac La Biche and Missawe Lake both of which lie just outside the sample area. Unfortunately the higher ridges tend to be wooded, whilst the shallow, fairly level ground is substantially farmed. In conclusion, the records of the Lac La Biche station underestimate considerably the

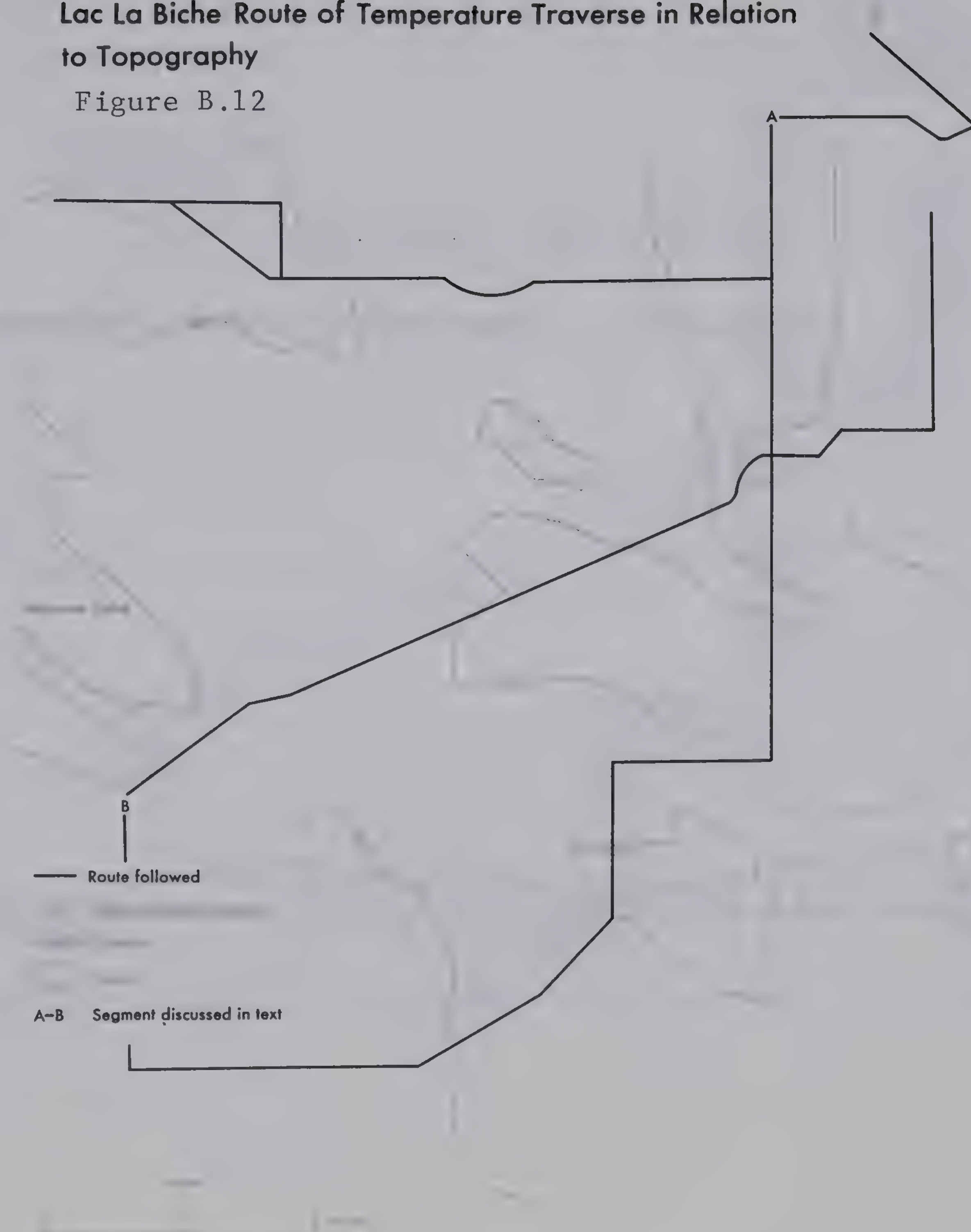
Lac La Biche Sample Area

Figure B.11



Lac La Biche Route of Temperature Traverse in Relation to Topography

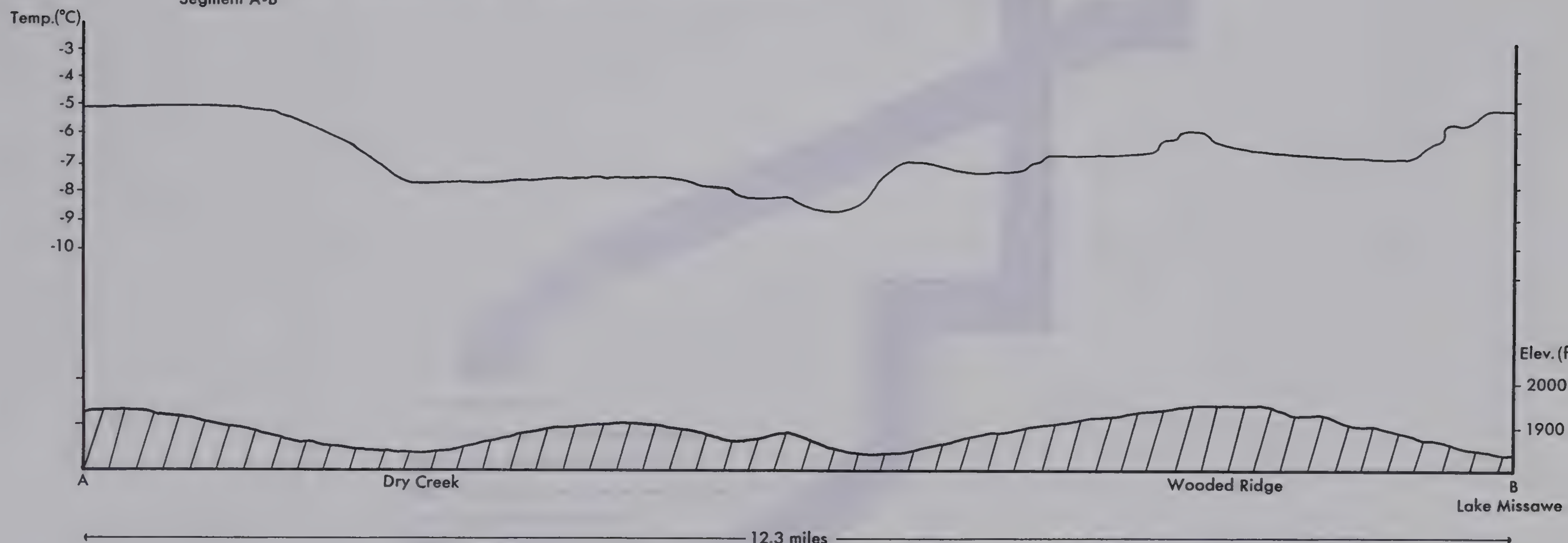
Figure B.12

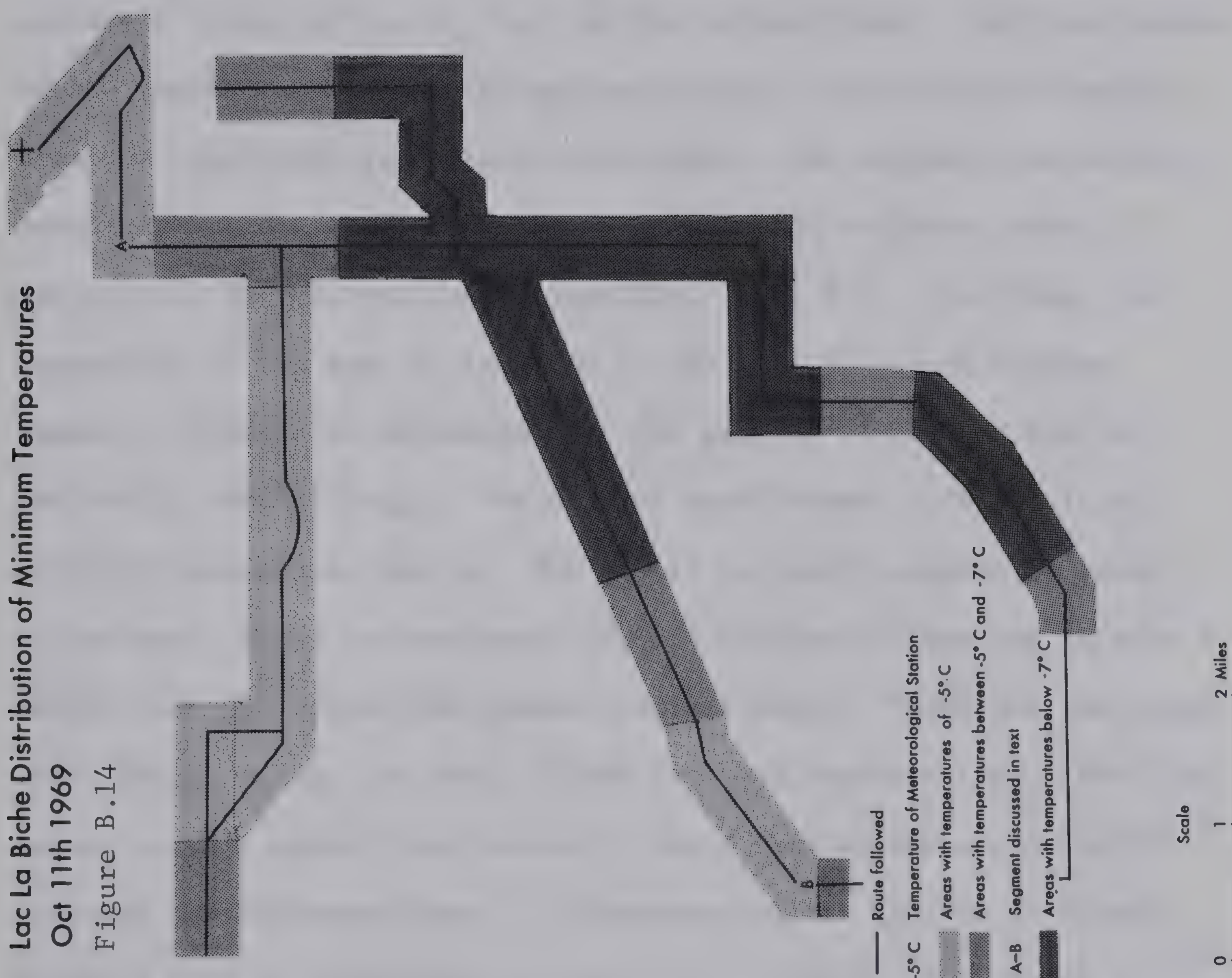


Lac La Biche; Temperature in Relation to Topography

Segment A-B

Figure B.13





Lac La Biche Distribution of Minimum Temperatures
Oct 11th 1969
Figure B.14

severity of the frost hazard within the sample area.

Athabasca Sample Area

This area is situated in Athabasca County, its coordinates being NW 1/4 34/67/24; NE 1/4 34/67/23; SE 1/4 33/66/23, and the southwest corner of lot 21, west of the 4th meridian. The distribution of the sample area around the meteorological station largely results from the limits of agricultural settlement. The northern and western boundaries of the sample area are virtually the northern limits of agriculture in this particular locality. Fig. B.1 illustrates the topography of the area in relation to the meteorological station (known officially as Athabasca II), the sampled farmsteads and the individual farm holdings. The map was again drawn on the basis of 1:50,000 topographic sheets. The relief is gently undulating except in the east, where the southward-flowing Athabasca River has incised a valley over 200' below the general surface level. There are two large water bodies within the area, Island Lake and Baptiste Lake. From the latter a small creek flows through a broad shallow depression before entering the Athabasca River. The meteorological station is located within a mile of Island Lake on the top of a gentle rise, which is the highest land in the area. The station itself (height 2050') lies between the house of the observer and a line of trees which serve as a windbreak to northerly winds. This station recorded during 1959-68 a significantly longer frost-free period than the old Athabasca station which Longley used in his analysis of the 1951-64 period. This latter station, now disbanded, was sited 15 miles to the southeast of the station considered here, and obviously tended to record the effects of cold air

drainage more than the Athabasca II station. As a result mean minimum temperatures at the old Athabasca station were much lower.

Table B.4 Mean Minimum Temperatures 1961

	June	July	August	September
Athabasca	44.9	44.1	45.8	32.4
Athabasca II	50.5	49.5	49.6	34.4

Source: Department of Transport, Meteorological Branch, Monthly Records 1961.

The Athabasca station was not used because after 1959 the records were intermittent and finally stopped in 1965.

The records, 1959-68, of the Athabasca II station indicate an average frost-free season just sufficient for the cultivation of cereals (Table B.5). The shortest frost-free periods were recorded in 1968 (55 days) and 1965 (72 days), whilst all the others received longer than 100 days frost-free. In terms of 28°F, all the years received more than 115 days. The probability of spring frosts after May 15 is 70% and 30% after June 1, and the probability of a fall frost before August 31 is 10% which increases to 60% by September 10. No killing frosts were recorded in June, July and August and the probability of a killing frost after May 15 is 10% and a fall frost by September 10 is 40%. Only in 1968 have frosts been recorded in July and August when two frosts occurred in August.

A temperature traverse was conducted around sunrise on October 4 (Fig. B.16). The skies were clear and the wind calm but there were extensive banks of mist and this appears to have had the effect of unifying temperature distribution. The temperature at the

start of the traverse, as recorded by the station was 26.2°F (-3.2°C) and at the finish 25.5°F (-3.6°C) so again no adjustment was needed. The highest temperature recorded during the traverse was -2.75°C (27.0°F) and the lowest -4.6°C (23.8°F), giving a maximum variation of only 1.8°C (3.2°F). The lowest temperature was, in fact, recorded in crossing the creek which runs from Baptiste Lake to the Athabasca River. This is a low lying area where the land is cold and damp so that heat gains are small with the result that this area is frost prone. This inversion is shown on Figure B.17 (segment A-B on Fig. B.16). Variations in temperature still tended to reflect topographical conditions although considerably modified by the effects of the mist. Alongside Baptiste Lake and at heights similar to the meteorological station, the traverse temperatures were uniform. On the lower land and in areas of bush, slight drops in temperature were registered. It is conjectured that on calm, clear nights without mist these variations would have been greater. However, the two lakes, and the nearby distribution of marsh provide a considerable source of moisture. This, in association with the relatively low and gently undulating relief, creates suitable conditions for frequent and extensive distribution of low-lying mist or fog. On the occasions when mist does develop this will tend to prevent minimum temperatures from dropping as much as they otherwise would have done, a point with which Professor Longley fully concurs (Pers. Comm., 1970). Even so it is probable that as a result of the local site conditions associated with the meteorological station, the frost hazard in this sample area is underestimated by the records of the Athabasca II station.

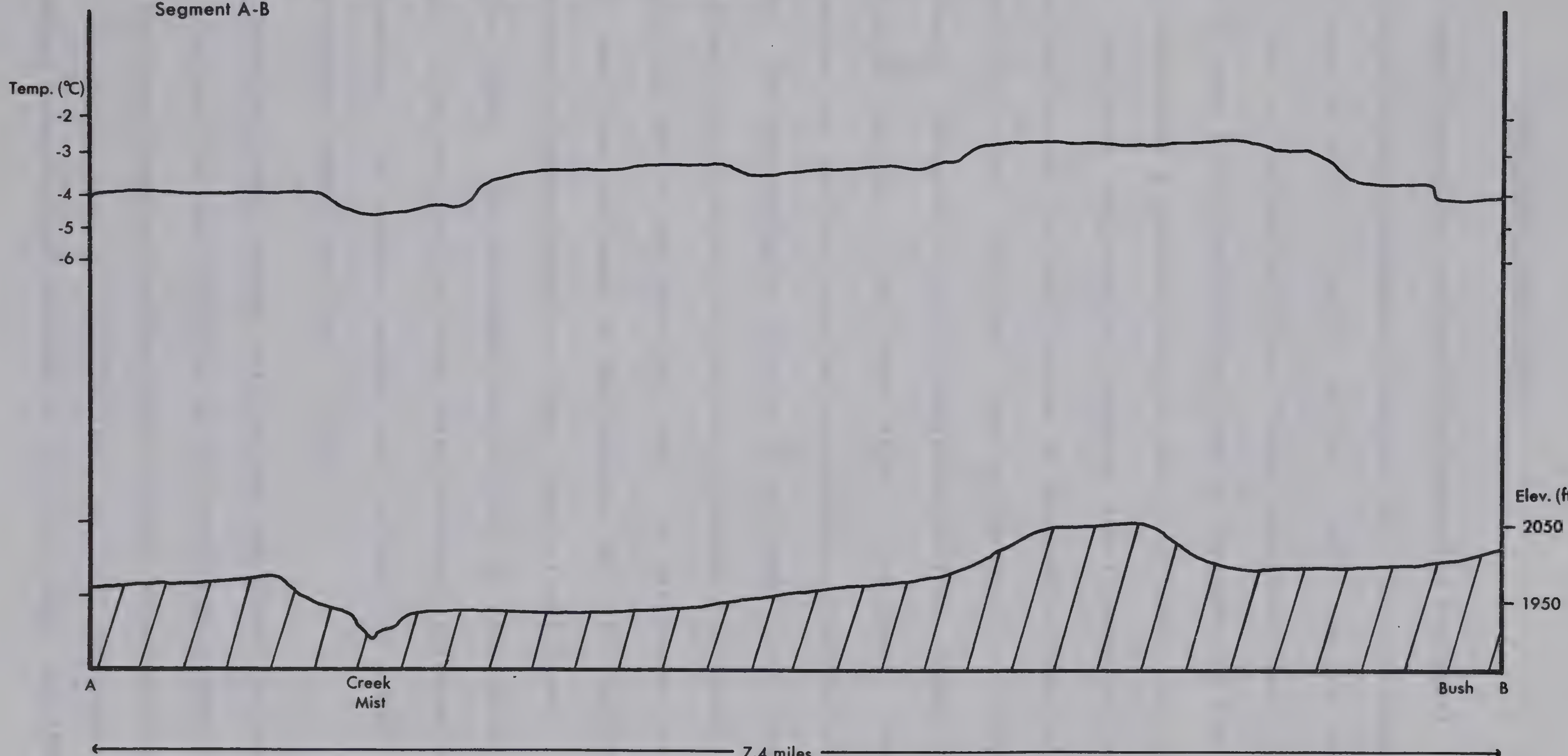
Figure B.15

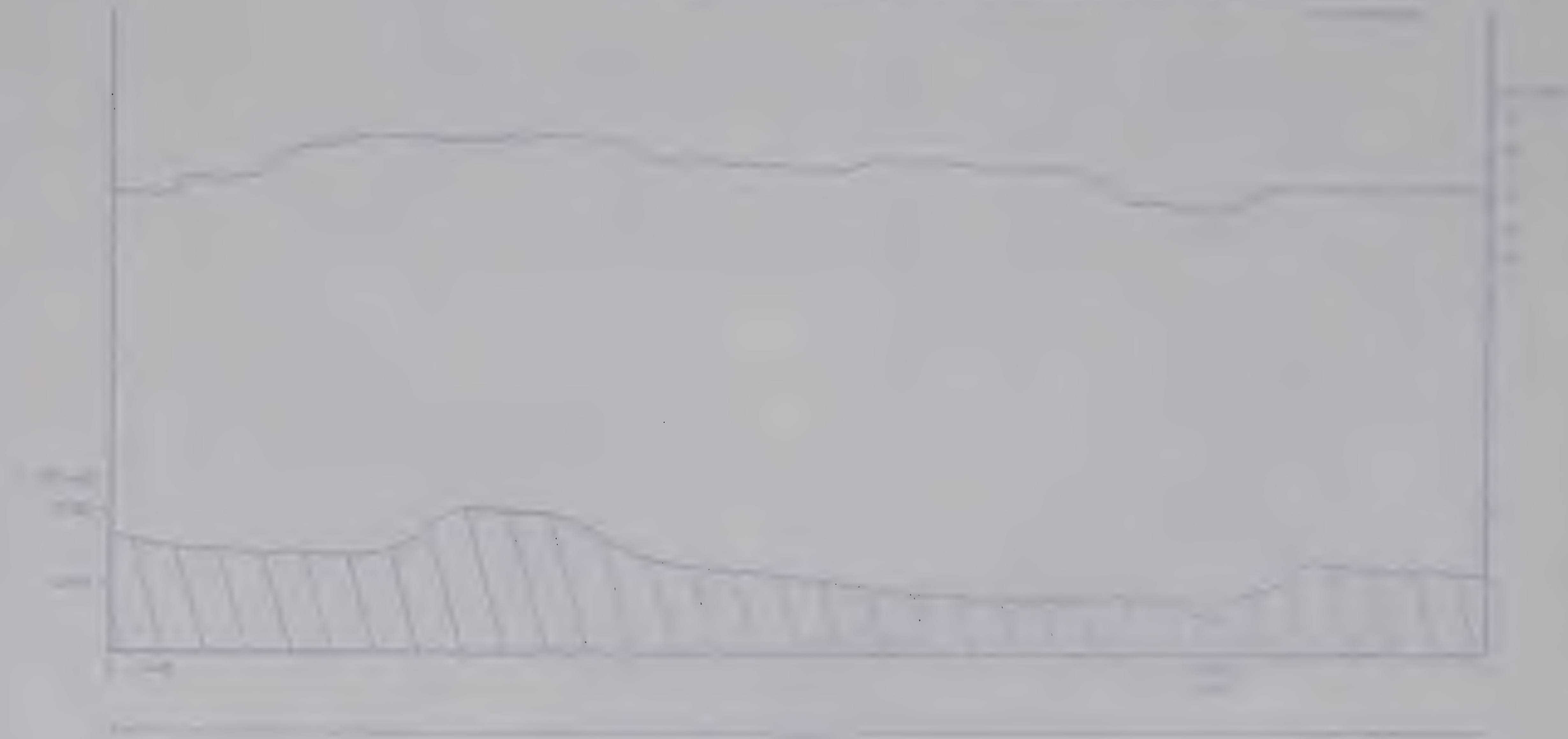
Athabasca Sample Area

Athabasca Route of Temperature Traverse in Relation to Topography   Figure B.16

Athabasca; Temperature in Relation to Topography Figure B.17

Segment A-B





Iron River Sample Area

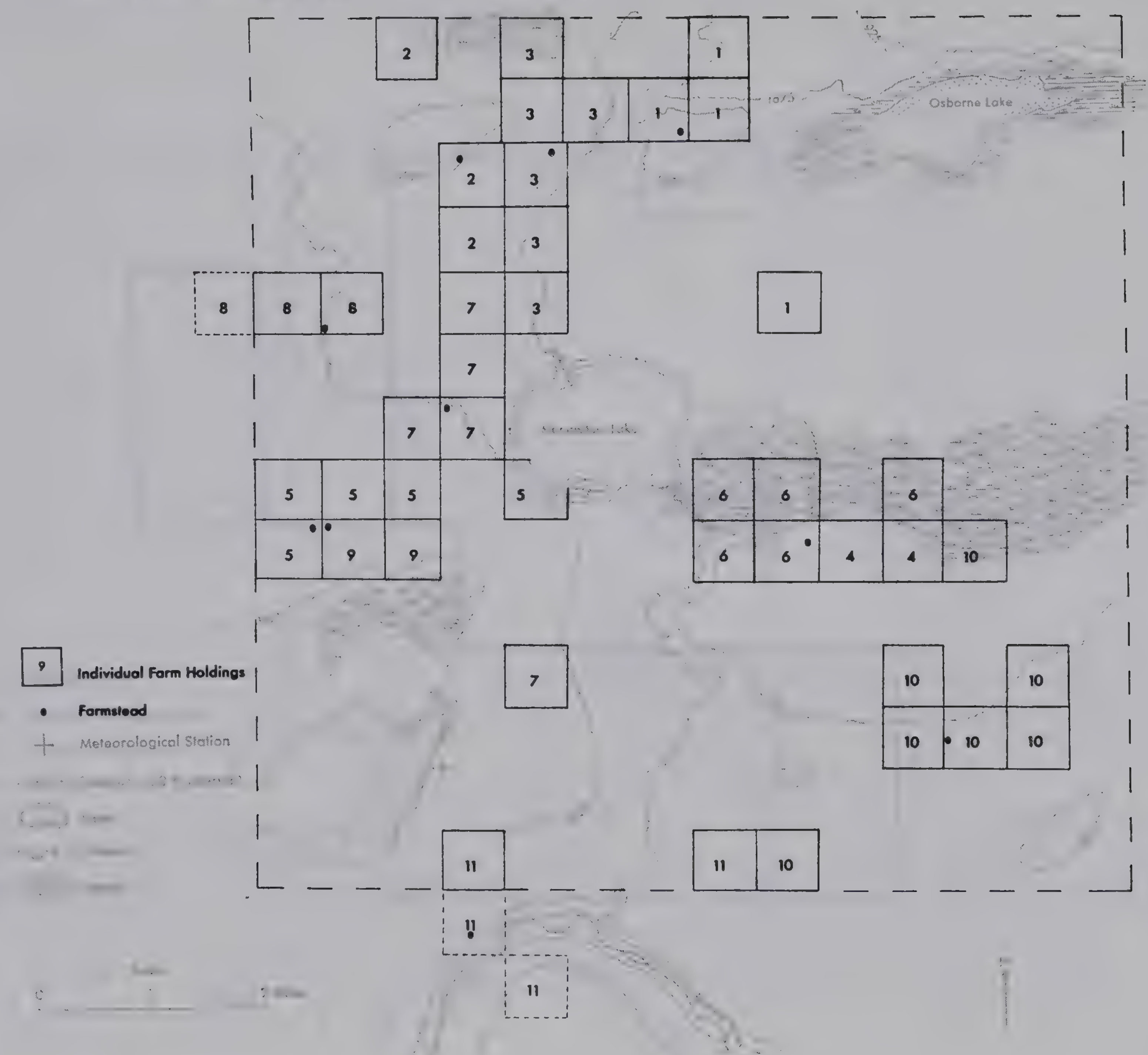
The sample area lies partly within Bonnyville Municipal District and partly within Improvement District 101. The coordinates of the sample area are NE 1/4 5/64/7; SE 1/4 5/63/7; SW 1/4 4/64/6; SW 1/4 4/63/6 west of the 4th meridian. These coordinates were chosen because there is very little agricultural land to the west and the Beaver River constitutes a physical barrier that is difficult to cross in the south. The broad topographical features, the location of the meteorological station and the distribution of the sampled farm holdings are illustrated (Fig. B.18). This map, drawn on the basis of 1:50,000 topographic sheets, indicates a gently undulating surface, rising to the north, from the incision of the Beaver River in the south. There are several medium size shallow lakes and an extensive distribution of marshy land. The meteorological station is on a small rise, the ground falling away quite rapidly to the south (towards the Beaver River) but levelling out to the north and east. The Stephenson Screen is located 30' away from the house of the observer in a well cultivated garden, surrounded by garden shrubs and trees, most of which are higher than the screen. The instrument shelter was, in fact, moved in 1957 because of an overgrowth of bush which obviously affected the temperature readings. The present garden growth around the screen must almost certainly reduce heat loss at night.

The detailed frost records for the last ten years are tabulated (Table B.6). The year to year variation in the frost-free season is not so great for Iron River as for the other stations except Elk Point. The shortest seasons occurred in 1960 (84 days) and 1968 (86 days), whilst the longest seasons were recorded in 1963 (121 days) and 1966

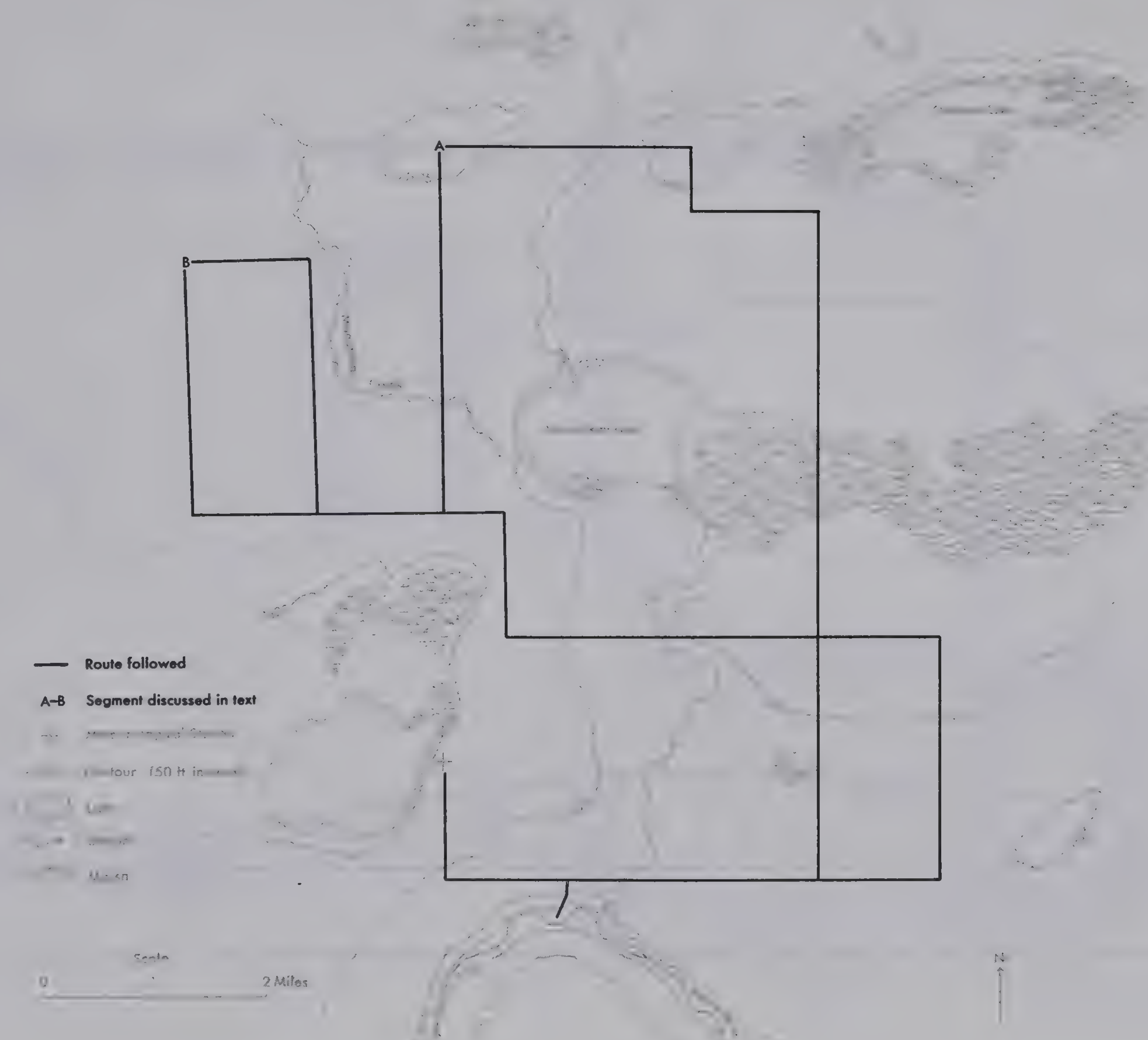
(121 days). On the basis of 28°F, there has not been one year in the last ten with a season of less than 109 days. The chances of a spring frost on May 15 or after is 80% and by June 1 the probability of a spring frost falls to 30%. There is a 10% risk of frost before August 31 and a 60% risk by September 10. The probabilities of killing frosts for the same dates, are 30% and nil in the spring, and nil and 40% in the fall.

Two temperature traverses were completed on October 8 and October 12. The first traverse has been ignored due to high wind speeds which destroyed any possibility of temperature inversions. The second traverse, operated under clear skies and without any wind, was started at 1:30 a.m. and finished at 2:58 a.m. several hours before sunrise, so that the problem of some adjustment to the temperature recordings became a possibility, if during the traverse period temperatures were dropping through nocturnal radiation. In fact the temperature drop recorded by the meteorological station during the 1 1/2 hour traverse was only 1.2°F, so assuming a constant drop in temperature, the adjustment problem was negligible. In terms of the cross-profile, which is only a small segment of the traverse, the temperature drop could be ignored completely. The temperature recorded by the station at the start of the traverse was 23.0°F (-5.0°C) and at the finish was 21.8°F (-5.7°C). The highest temperature registered on the traverse was -4.5°C (23.9°F) and this was, in fact, recorded along part of the route just to the west of the sample area. Figure B.19 gives the route of the traverse, which was partly outside the sample area in order to prevent too much 'retreading'. Temperature inversions of 2.7°C (5.9°F), 2.4°C (4.5°F) and 4.5°C (8.1°F) occurred during the course of the

Iron River Sample Area Figure B.18

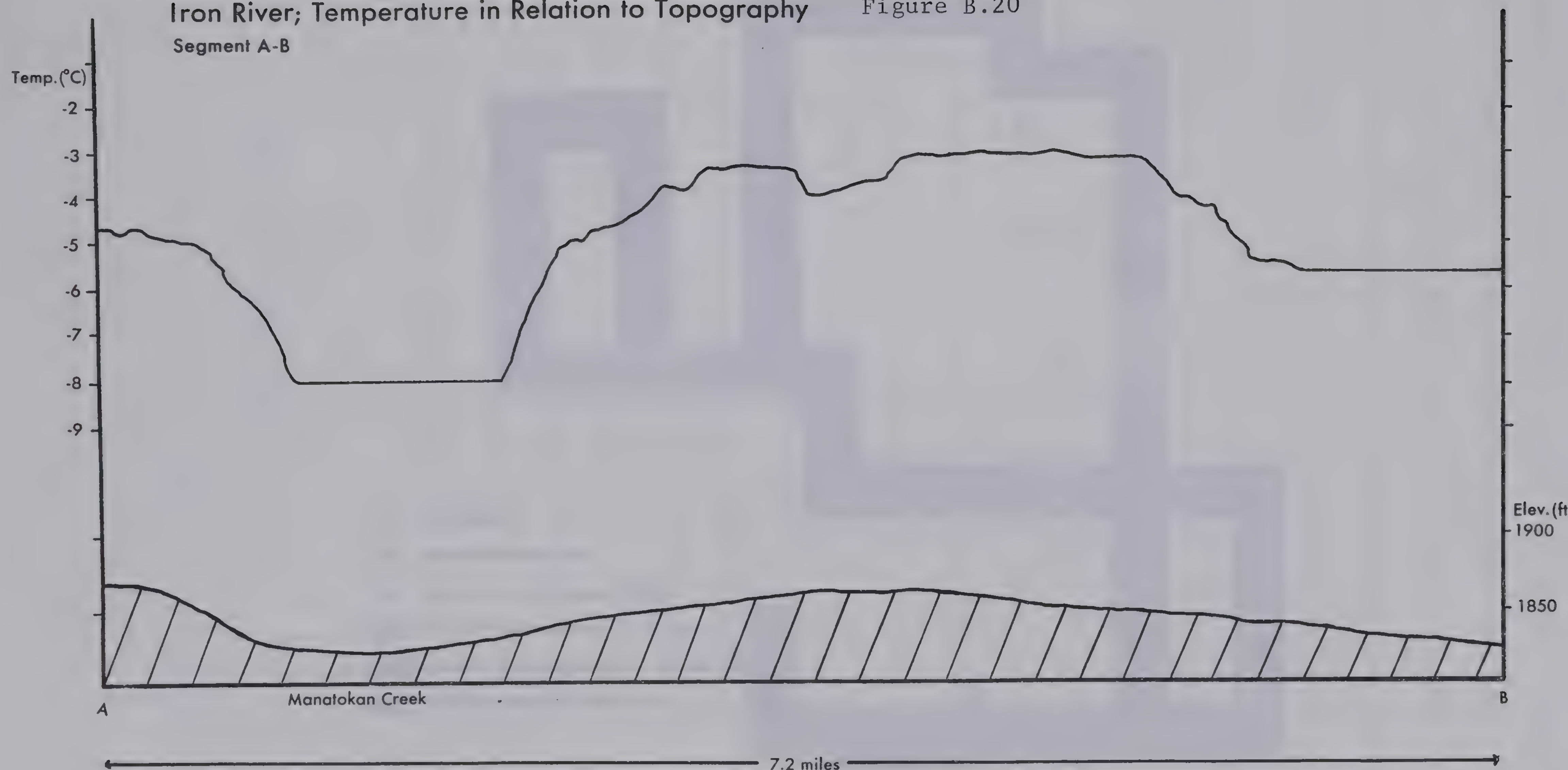


Iron River Route of Temperature Traverse in Relation to Topography — Figure B.19



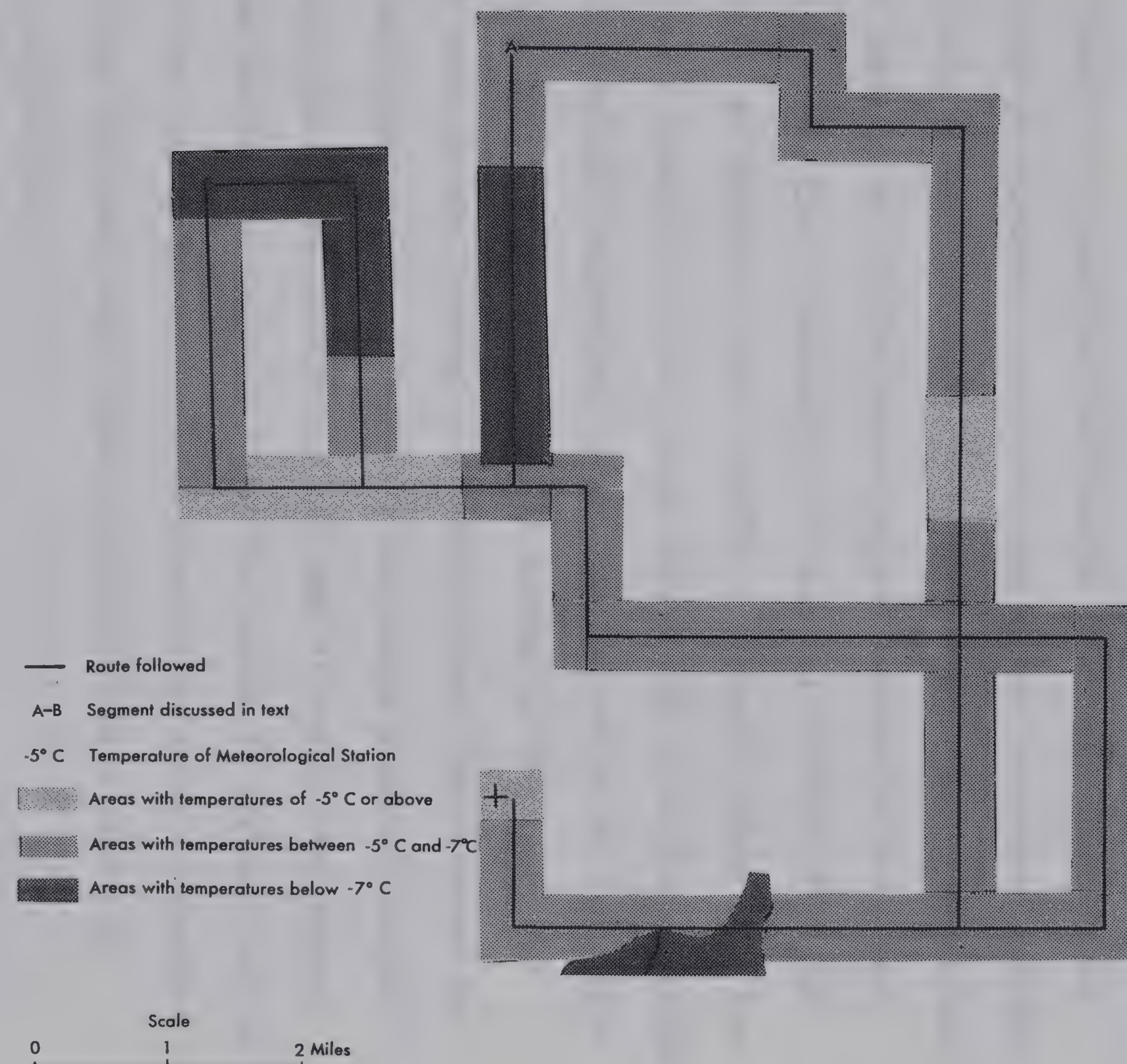
Iron River; Temperature in Relation to Topography   Figure B.20

Segment A-B



Iron River Distribution of Minimum Temperatures Oct 12th 1969

Figure B.21



traverse. Figure B.20 illustrates two of these inversions (segment A-B on Fig. B.19), the largest occurring at the bottom of a broad, shallow hollow occupied by Manatokan Creek. The other inversion is again due to decreasing relief as the bottom of Mantokan Creek is approached, and also to the presence of muskeg.

Figure B.21 gives the distribution of minimum temperatures along the route in relation to that recorded by the Iron River station. This shows quite clearly that apart from two or three small localities, the minimum temperature of the meteorological station is above that for the rest of the area, frequently by as much as 1.1°C (2.0°F) and on one occasion by virtually 5.6°C (10.0°F). It would appear then that the Iron River's station site, on rising land within a cultivated garden and surrounded by tall vegetation, is not representative of the sample area. Broad, shallow dips in the general surface of the land, now occupied by small creeks, muskeg, uncultivated land, new breaking and marsh are the characteristic features of the sample area and they are all extremely frost-prone localities. In many of these lower spots, most of them indicated on Figure B.18 by the course of streams, and in the Beaver River valley (which was also found to be a frost hazardous locality in the Cold Lake sample area), frost must be a hazard in every month of the year.

Elk Point Sample Area

Situated within the County of St. Paul, the coordinates of the sample area are NW 1/4 27/57/7; SW 1/4 27/56/7; NE 1/4 27/57/6; and SE 1/4 27/56/6 west of the 4th meridian. The area lies on the north bank of the North Saskatchewan River and is the most southerly of

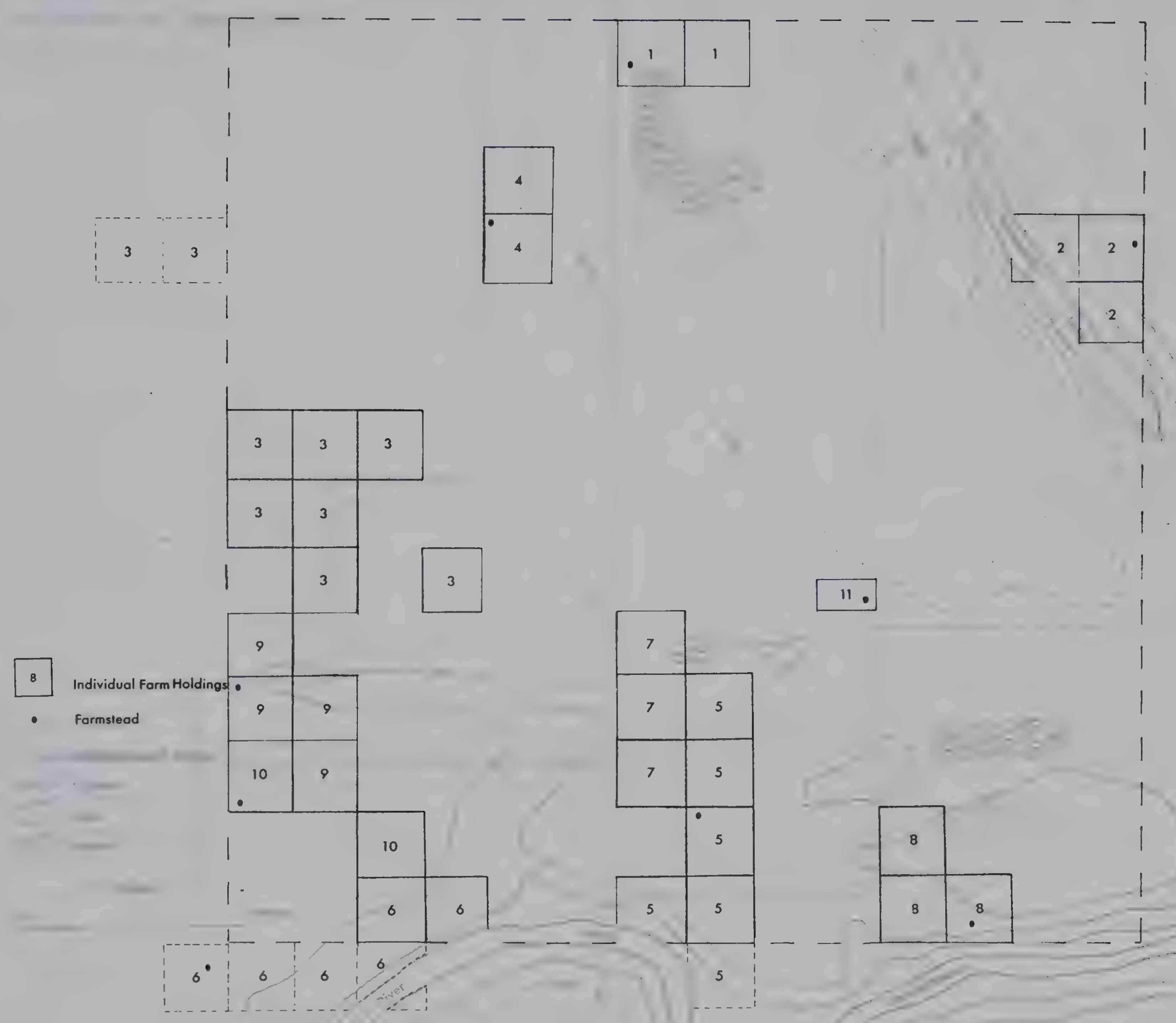
all the sample areas. The northern half of the area consists of a high plateau which rises to over 2100'. The plateau is characterised by open farmland except for a large steep-sided valley, occupied by Moosehills Lake, in the northeast. In this area the steep slopes have an extensive covering of wild bush. The valley sides and floor of the North Saskatchewan are also covered extensively by forest and bush with the occasional cultivated field. The meteorological station is in the small town of Elk Point which is situated on a 'terrace' which interrupts the general downward slope towards the North Saskatchewan. The highest point is on the northern edge of the sample area, and there is a relatively steep drop of over 300' interrupted by two 'terraces', to the valley bottom of the Saskatchewan. The main relief features in relation to the site of the meteorological station and the spatial distribution of sampled farm holdings are given by Figure B.22, drawn on the basis of a 1:250,000 topographic sheet. The Stephenson Screen is situated 15' north of a house in Elk Point, in a well cultivated garden in close proximity to a hedge and a row of trees 25' high. It is thought that these features are significant in reducing heat loss at night.

The records for 1959-68 show a remarkable consistency (Table B.7). The longest frost-free seasons was in 1963 (119 days) and the shortest was in 1968 (84 days) when the first fall frost occurred in August 10. Frosts were recorded in August in 1968 and 1960 but none has been registered in July. On the basis of the 1959-68 period the chance of a spring frost after May 15 is 100% whilst the chance of a June frost is 30%. Probabilities of fall frosts before August 31 are 20% and by September 10 are 60%. Using 28^{o}F probabilities for the same

dates are 40% and 10% in the spring, and nil and 30% in the fall. There are considerable variations in topography within the sample area and it might be supposed that this would result in large temperature differentials. To test this hypothesis a traverse was conducted around sunrise on October 13. At the start of the traverse skies were clear and winds calm but during the traverse, an increasing cloud cover, blowing in from the north, signalled the influx of warm air. By the end of the traverse the sky was completely covered by clouds. The increase in temperature recorded by the meteorological station was 2.5°C (4.5°F). However, it cannot be assumed that the increase in temperature was constant during the traverse, and, more importantly, any temperature inversions occurring along the route must have been seriously reduced, if not removed altogether. The total effect then of the incoming cloud cover and warm air was to unify temperature distribution.

Thus despite a considerable range of topographic features, the maximum variation along the traverse route (Fig. B.23) was only 2.7°C (4.9°F). Because of this and the insoluble adjustment problem a map showing temperature distribution along the traverse route was not drawn. Figure B.24 (segment A-B on Fig. B.23) illustrates the largest temperature inversion recorded during the traverse. This occurred during the first half of the traverse and presumably before the inflowing warm air had taken its full effect. The inversion occurred in the vicinity of a small dry creek. The diagram also shows a slight increase in temperature as the higher levels of the plateau are reached. Along other parts of the route small inversions were noted near muskeg especially in the northeast near Moosehills Lake. Overall conclusions must be, therefore, somewhat conjectural. The station itself seems

Elk Point Sample Area Figure B.22

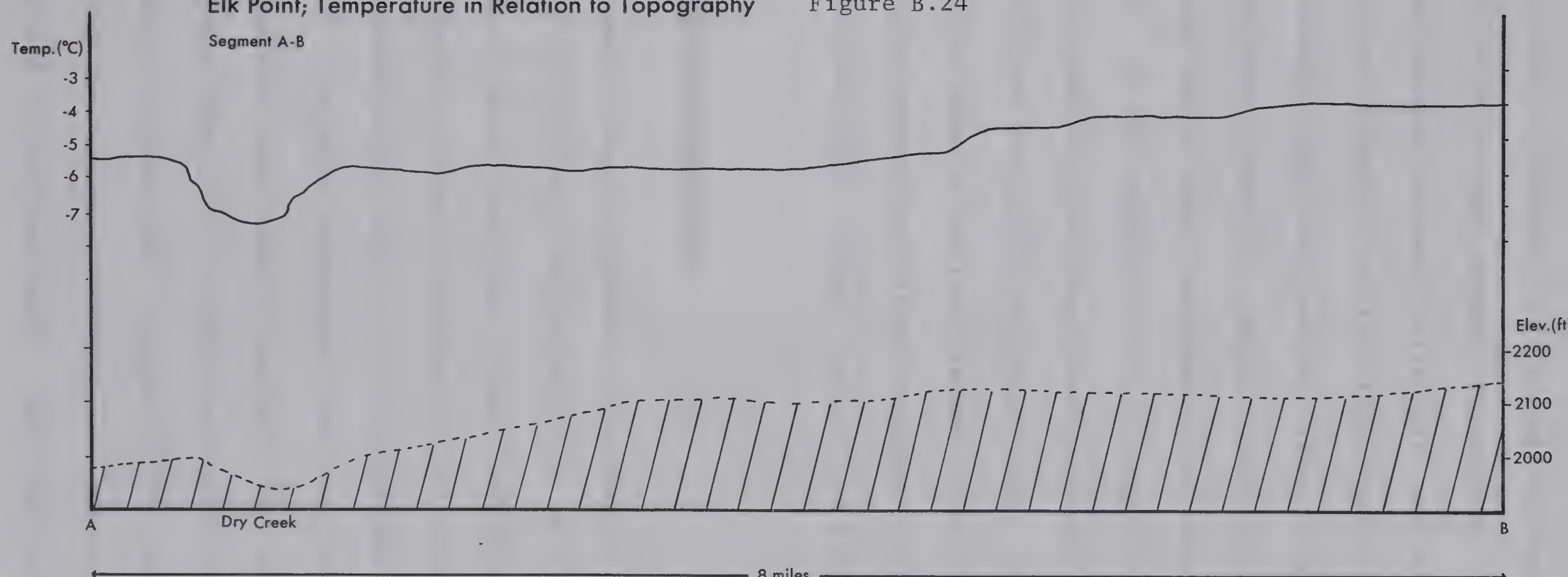


Elk Point Route of Temperature Traverse
in Relation to Topography

Figure B.23

Elk Point; Temperature in Relation to Topography Figure B.24

Segment A-B



to be poorly located in terms of nearness to buildings and vegetation, the effect of which must be to increase minimum temperatures. However, it is surmised that these records represent fairly well most of the higher land to the north and northwest, and the higher land of the northeast beyond the Moosehills Lake area, and the valley bottom and sides of the North Saskatchewan, where the combined effect of extensive forest cover and the large body of water contained by the rivermust reduce the risk of frost. At the bottom of the deep trough occupied by the shallow Moosehills Lake the frost hazard must be severe. However, this is an extremely localised area within the sample area. Other areas which are underestimated in terms of the frost hazard by the Elk Point records are probably shallow depressions within the general plateau surface and perhaps along the first 'terrace' level of the Saskatchewan valley.

Newbrook Sample Area

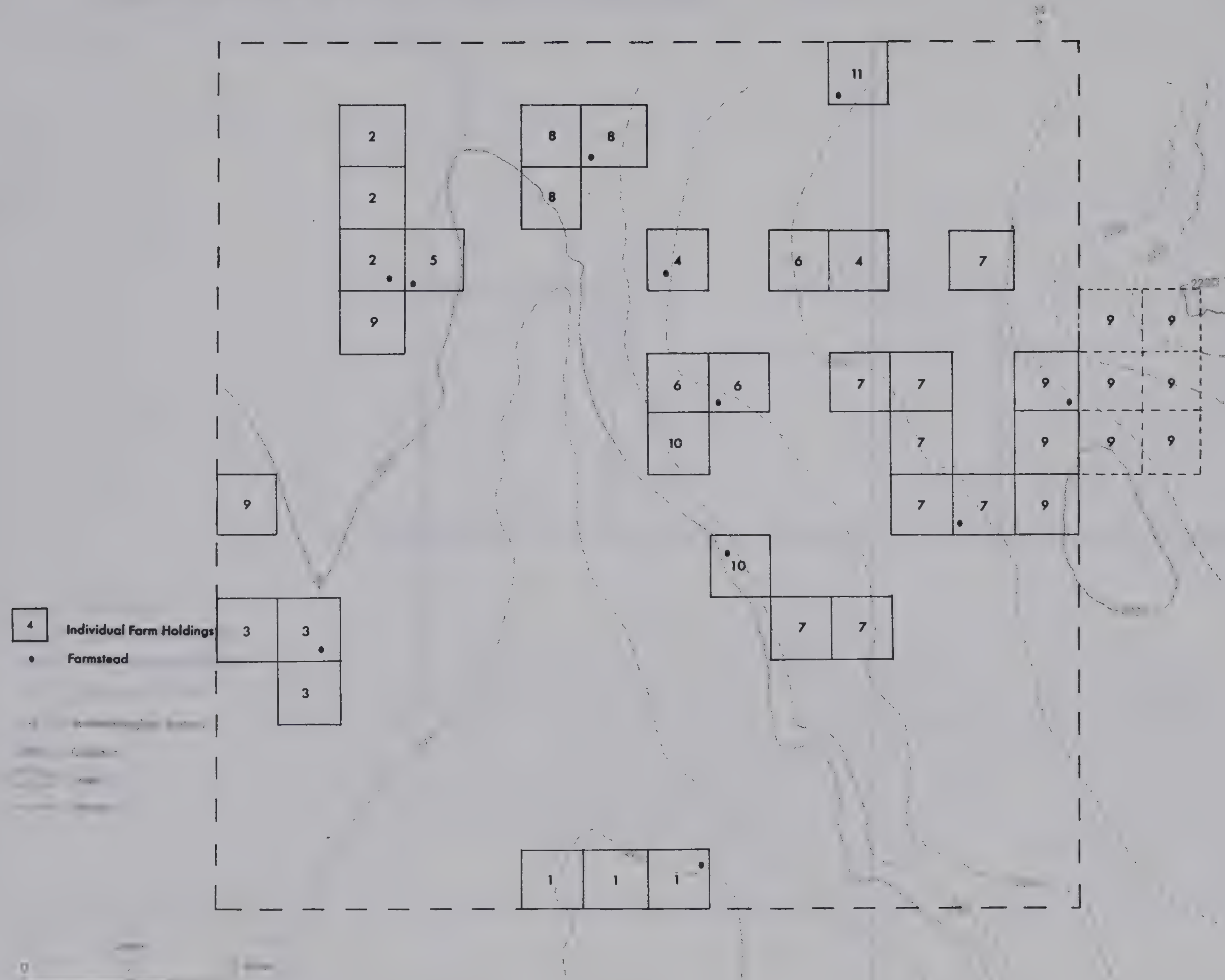
The Newbrook sample area is situated in the County of Thorhild, its coordinates being NW 1/4 20/20/62; SW 1/4 20/20/61; NE 1/4 20/19/62 and SE 1/4 20/19/62 west of the 4th meridian. Figure B.25 illustrates the site of the meteorological station in relation to the topography of the area. This map was drawn on the basis of a 1:250,000 sheet with a contour interval of 100'. Altimeter measurements taken in the fall of 1969 by myself provide supplementary spot heights from which the relief features of Figure B.25 were drawn. On this map the distribution of marsh was omitted because on the base map, surveyed in 1951, marsh covered almost the entire area and for the sake of clarity was left out. The area is mainly open farmland with little tree cover. The relief is on the

whole very gently sloping with a gradual rise to the east. Along a few places on the eastern margin the rise is sharp. The meteorological station (height 2209') is located on the western side of the sample area on the periphery of the small town of Newbrook. The lack of farmland to the west of Newbrook is the reason for the sample area not being centred on the meteorological station. The station is well exposed, lying on level ground, with no observable relief changes in any direction, and is situated away from trees and houses. The nearest building is the observatory which is a small structure, situated approximately 20' from the Stephenson Screen. The temperature records of this station therefore, should not be considered abnormal in terms of micro-climatic criteria.

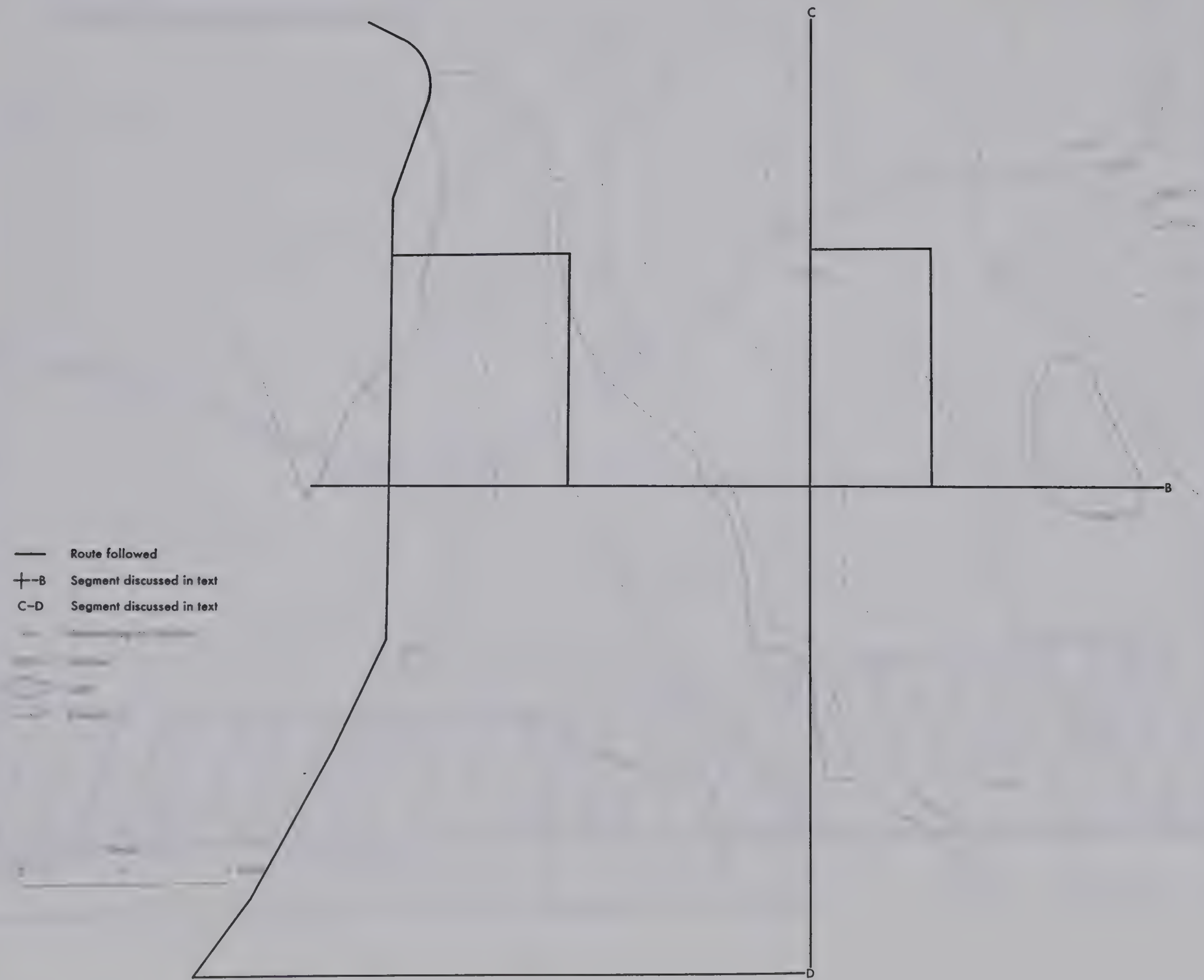
The frost records for 1959-68 show a remarkably short frost-free season (Table B.8). Only 1961 recorded a frost-free season of more than 100 days. Years with particularly short frost-free seasons were 1966 (23 days), 1959 (45 days) and 1968 (48 days). On the basis of 28°F a killing frost-free period of only 60 days was recorded in 1968, frost (32°F) occuring in every month of that year. In the most recent crop season under discussion here, 1968, the first fall frost was recorded on August 9 and the first killing frost on August 13. Frosts (32°F) occurred in July and August in six of the ten years of the study period. The chances of spring frosts after May 15 are 100% and 60% by June 1 whilst the probability of a fall frost by August 31 is 60% and 100% by September 10. Using 28°F, respective probabilities for the same dates are 80% and 20% in the spring, and 10% and 60% in the fall. Thus, even in terms of the killing frost-free period, the Newbrook records can only be regarded as marginal for the cultivation of cereals.

To test the representativeness of the station records for the sample area a temperature traverse was conducted on October 7 along the route indicated on Figure B. 26. The temperature at the start of the traverse was -5.0°C (23.0°F) and at the end -5.5°C (22.1°F) so that adjustment was not necessary. The maximum temperature recorded was 2.0°C (35.6°F) and the minimum was -7.5°C (18.5°F) which gives a variation in minimum temperatures within the area of 9.5°C (17.1°F). This large variation is illustrated by a temperature/topography profile (Fig. B.27) taken between the meteorological station and the eastern boundary of the sample area (segment from Meteorological Station to B on Fig. B.26). East of the meteorological station the temperature drops by 2.5°C (4.5°F) in the vicinity of a very shallow hollow, now occupied by a dry creek. As relief rises above 2200', the temperature correspondingly rises until at a height of 2300', at the very edge of the sample area, the temperature is 7.0°C (12.6°F) greater than that of the station. The north-south cross-profile (Fig. B.28) also shows a strong relationship between relief and minimum temperature with the inversion in this case being 5.0°C (segment C-D on Fig. B.26). Figure B.29 shows the distribution of minimum temperatures along the traverse route. If reference is made to the relief (Fig. B.26) it can be concluded that the station's records do not overestimate the frost hazard for those areas at a height of 2250' or below. Areas with a frost hazard even greater than that suggested by the station's records are below 2175. To the east and north of the sample area where the land is above 2250' the frost hazard is less, and considerably less for those areas at approximately 2300' than the records of the Newbrook station would indicate. Cold air drainage is obviously the principal mechanism creating this

Newbrook Sample Area Figure B.25

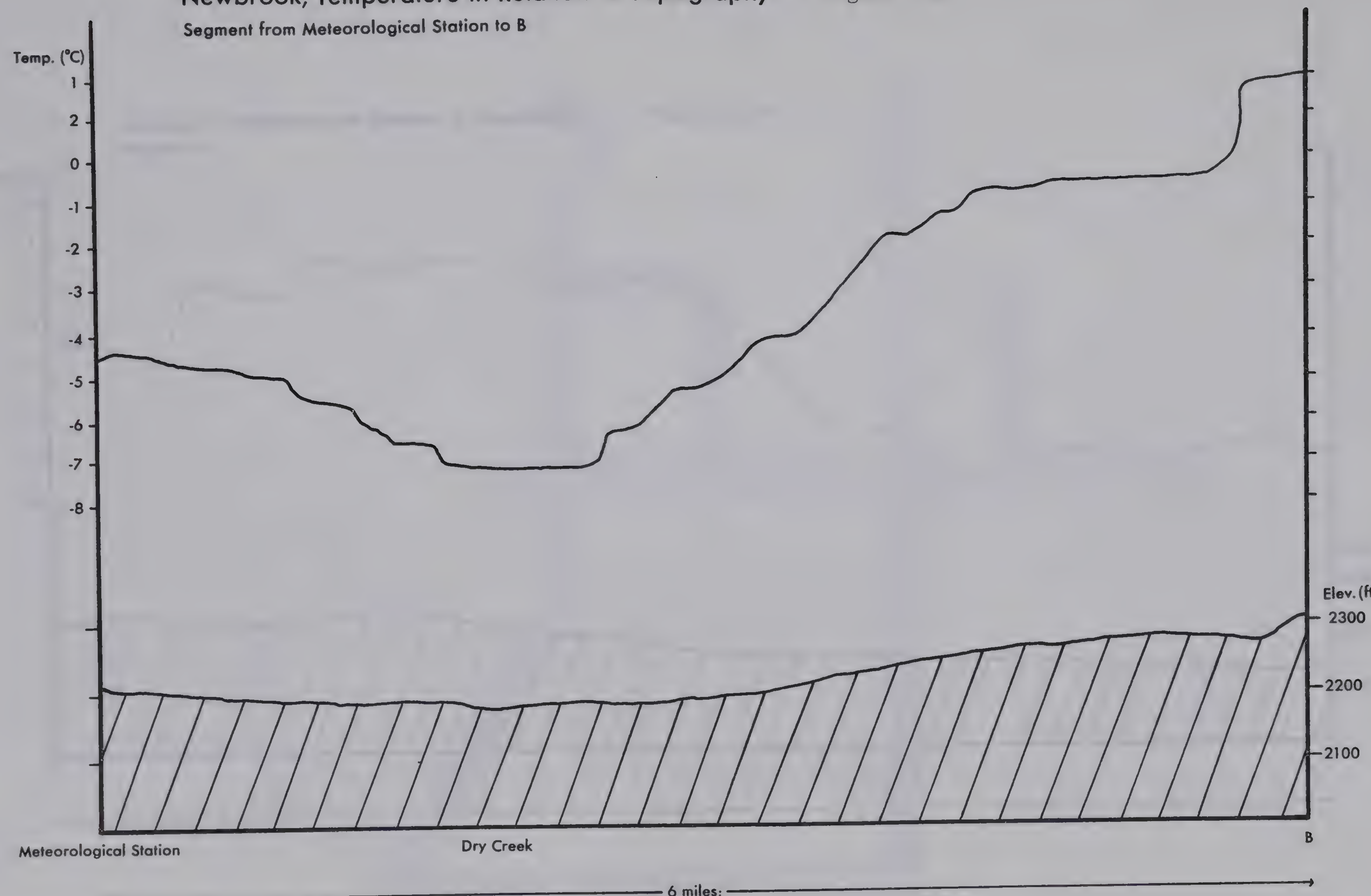


Newbrook Route of Temperature Traverse in Relation to Topography Figure B.26



Newbrook; Temperature in Relation to Topography   Figure B.27

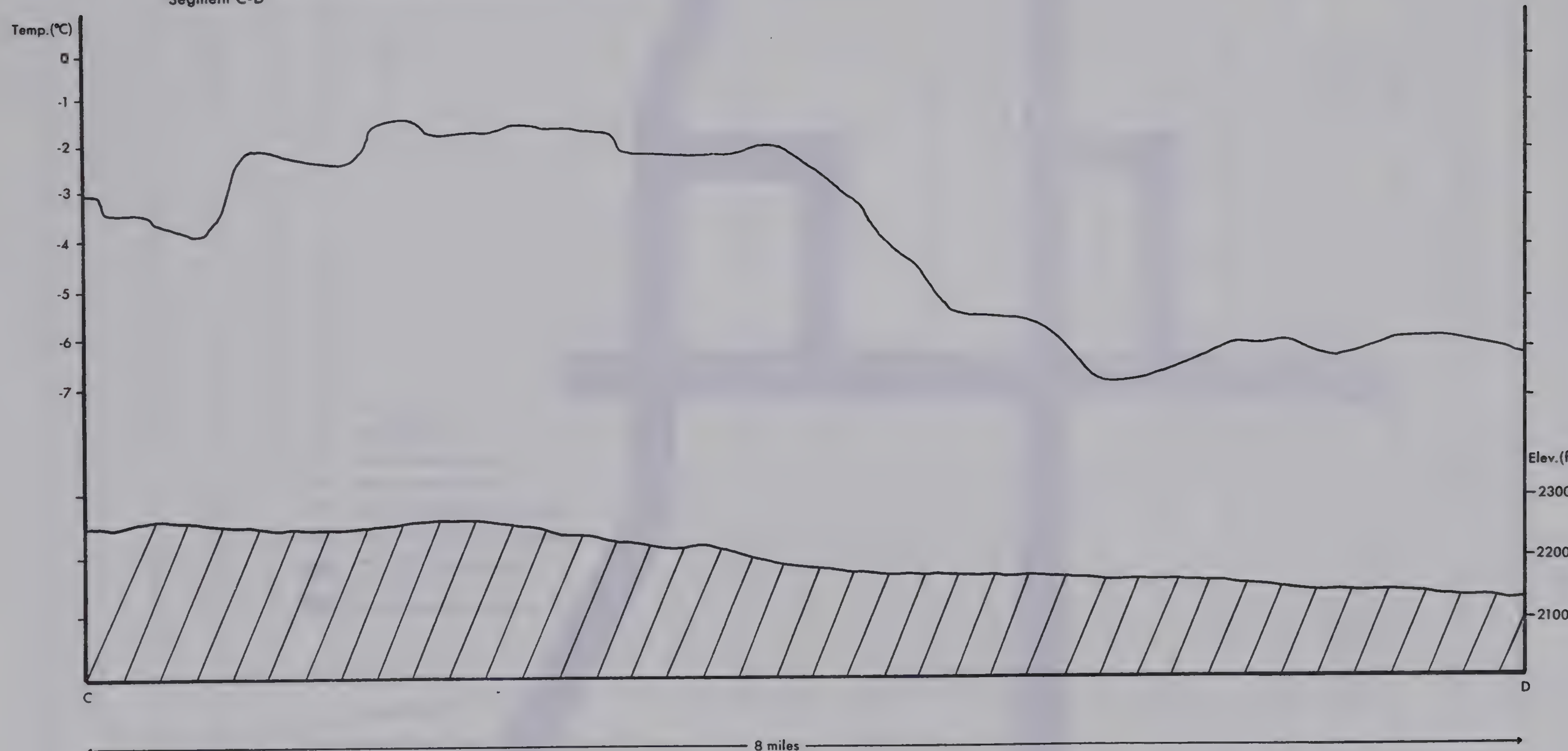
Segment from Meteorological Station to B



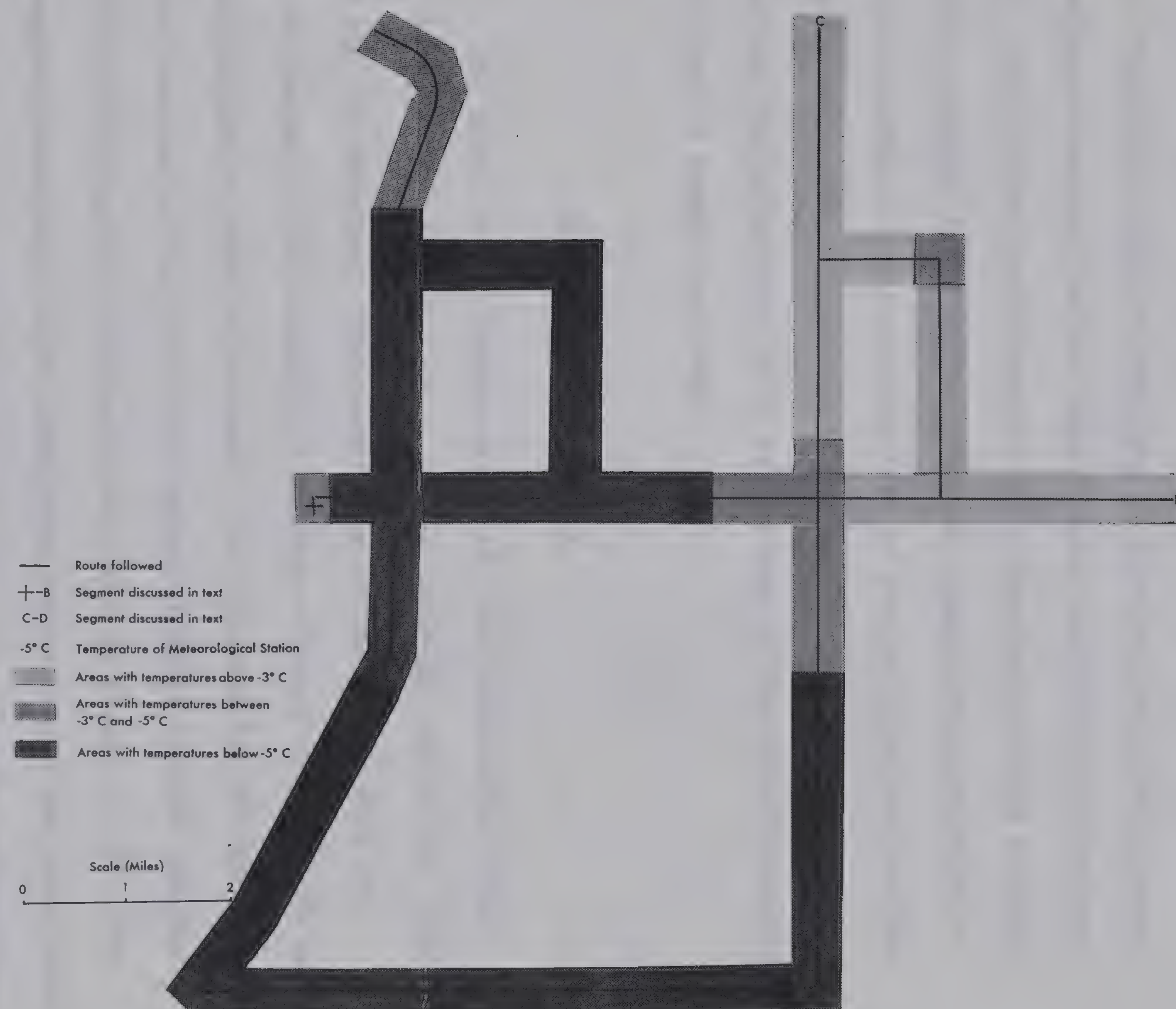
Newbrook;Temperature in Relation to Topography

Segment C-D

Figure B.28



Newbrook Distribution of Minimum Temperatures Oct 7th 1969 Figure B.29



spatial variation in the frost hazard. However, the greater part of this sample area is below 2250' and, with the reservations noted above, must be regarded as an area of extreme frost hazard. The sample area, on the whole, is nearly level but conceivably part of a large frost hollow. This would allow the settling of cold air on a fairly large scale and would explain the low temperatures recorded by the Newbrook station. The station itself should not be regarded as being situated in a small localised frost hollow. Another reason which might help explain the extreme frost susceptibility of most of this area is that the 1950 survey noted a large distribution of marsh (now virtually non-existent) and the ground may still retain some of the 'cold' characteristics of such a vegetation cover.

Rochester Sample Area

The area lies in Athabasca County, its coordinates being NW 1/4 9/63/24; SW 1/4 8/62/24; NE 1/4 9/63/23; and SE 1/4 8/62/23 west of the 4th meridian. The coordinates of the sample area were mainly determined by the Boundary of Athabasca County in the south and the distribution of marsh in the west. The relationship of topographical features to the site of the meteorological station and the sampled farm holdings and farmsteads are shown by Figure B. 30. The area consists essentially of an undulating plateau which has been deeply dissected in the east by the Tawatinaw River. The plateau surface drops gradually westwards to about 2125' where the meteorological station was located before it was disbanded in 1968. The station was also close to an extensive area of marsh, at least as far as the 1950 cartographic surveyors were concerned. The station was well exposed

and not affected by tall buildings or tall vegetation. Although the station was not sited at the bottom of a slope, as regards minimum temperatures it may be expected that the records were influenced by cold air drainage from the higher levels of the plateau.

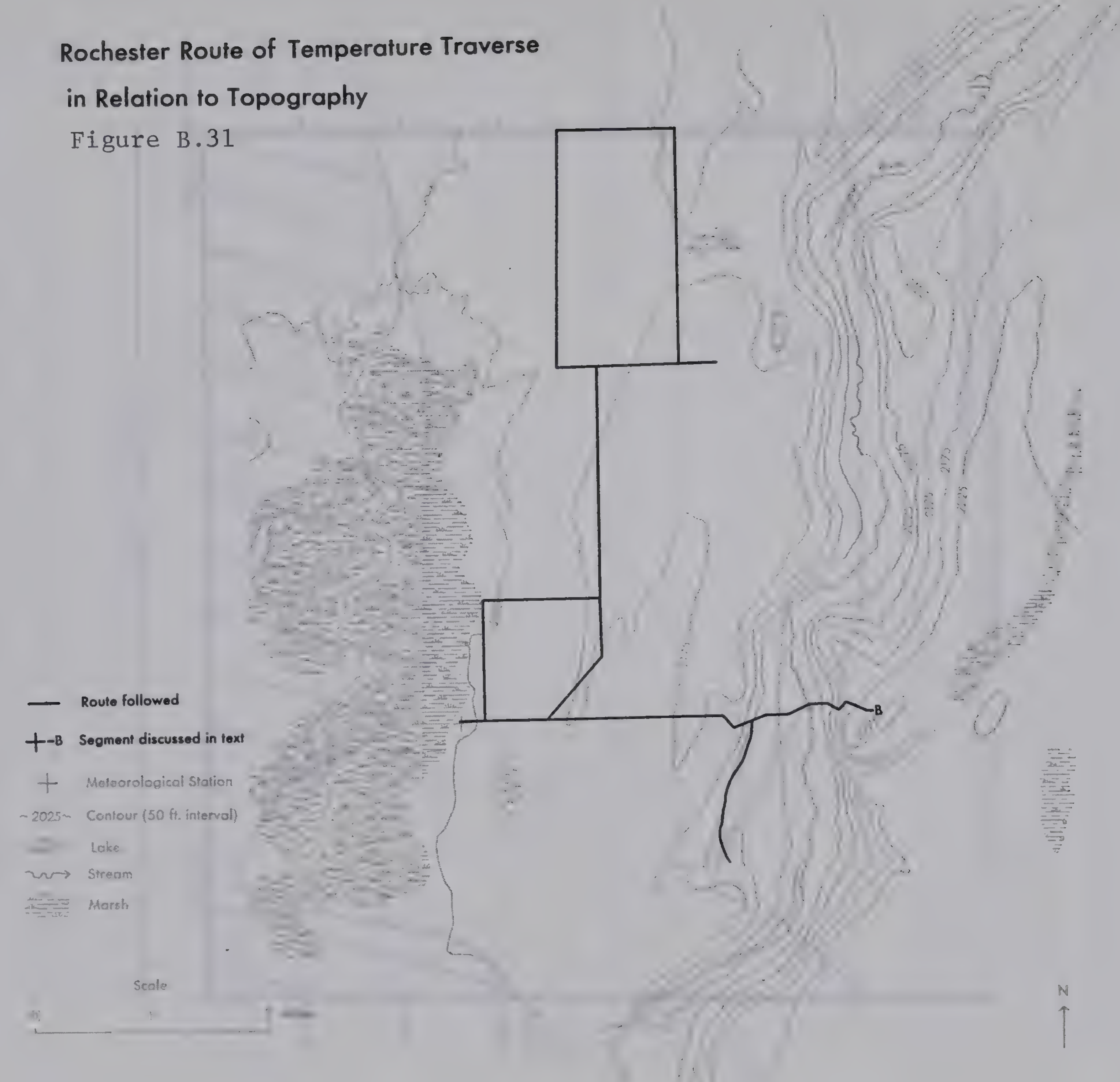
The records certainly show extremely short frost-free seasons during 1959-67 (Table B.9). It can be noted that if the station had continued throughout 1968, the extensive frosts beginning on August 9 which affected most of northern and central Alberta would have been recorded at this location. 1964 (31 days), 1967 (34 days) and 1959 (62 days) stand out as particularly short frost-free periods. Only 1961 and 1962 recorded frost-free seasons of more than 100 days. Between 1959-67 July and August frosts were recorded in four of the years. Assuming spring and fall frosts for 1968 to be similar to those recorded at Newbrook and Vilna (and in fact for this particular year for most stations in northern and central Alberta) the probability of spring frosts after May 15 is 100% and after June 1 is 80%. The probability of fall frosts by the end of August is 50% and by September 10 the chance is 100%. Probabilities based on 28°F for the same dates are 80% and 10% in the spring and 10% and 40% in the fall. A detailed examination of the Rochester records does not suggest any permanent chance of success in the cultivation of cereals.

A temperature traverse was conducted on October 6 along the route indicated by Figure B.31. Although the skies were clear, wind speed was between 10-15 mph and this had a considerable effect in unifying the temperature distribution. Figure B.32 shows the only significant temperature change during the entire traverse (segment from Meteorological Station to B on Fig. B.31). In spite of the wind speed

Rochester Sample Area Figure B.30

Rochester Route of Temperature Traverse
in Relation to Topography

Figure B.31



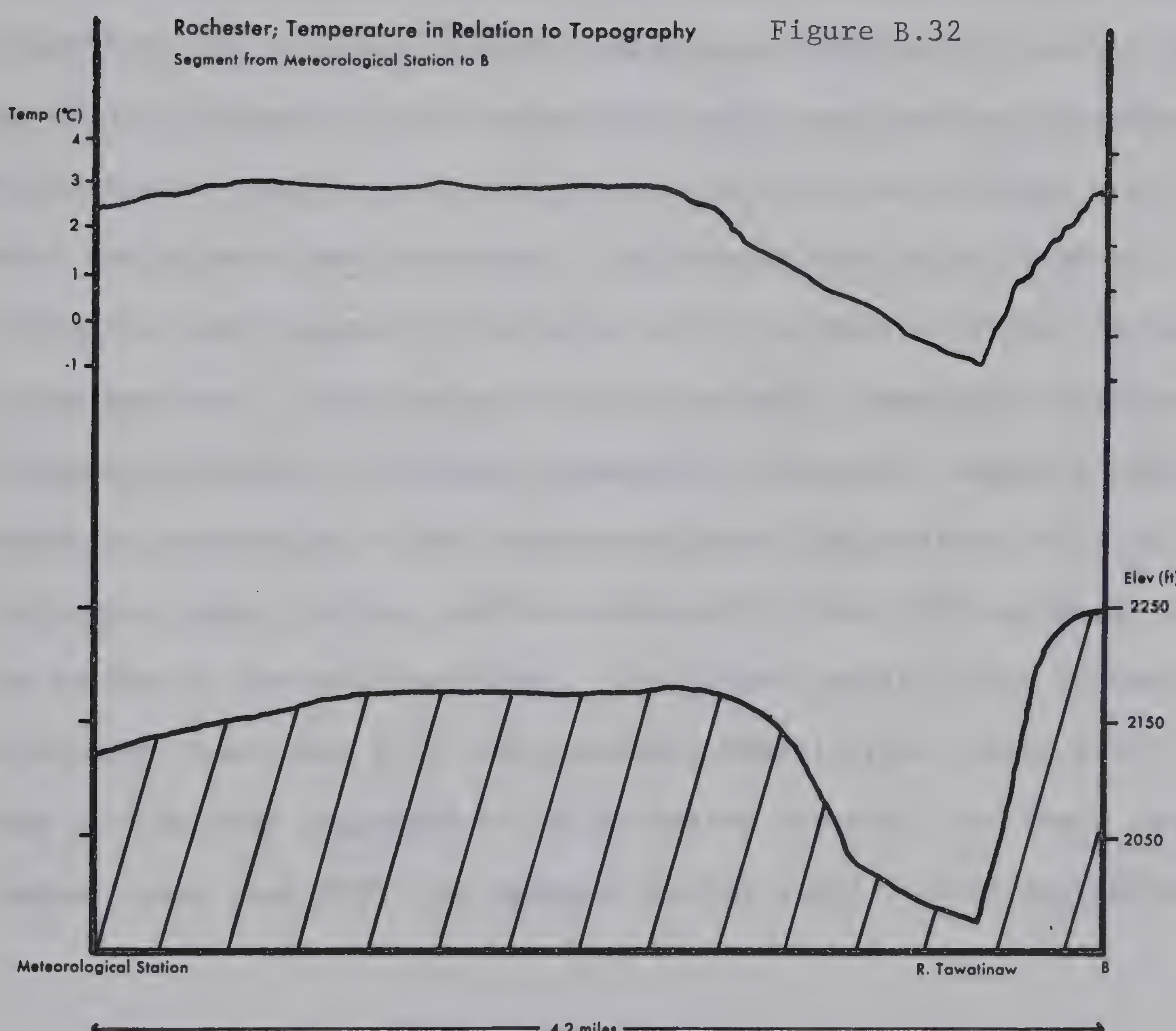
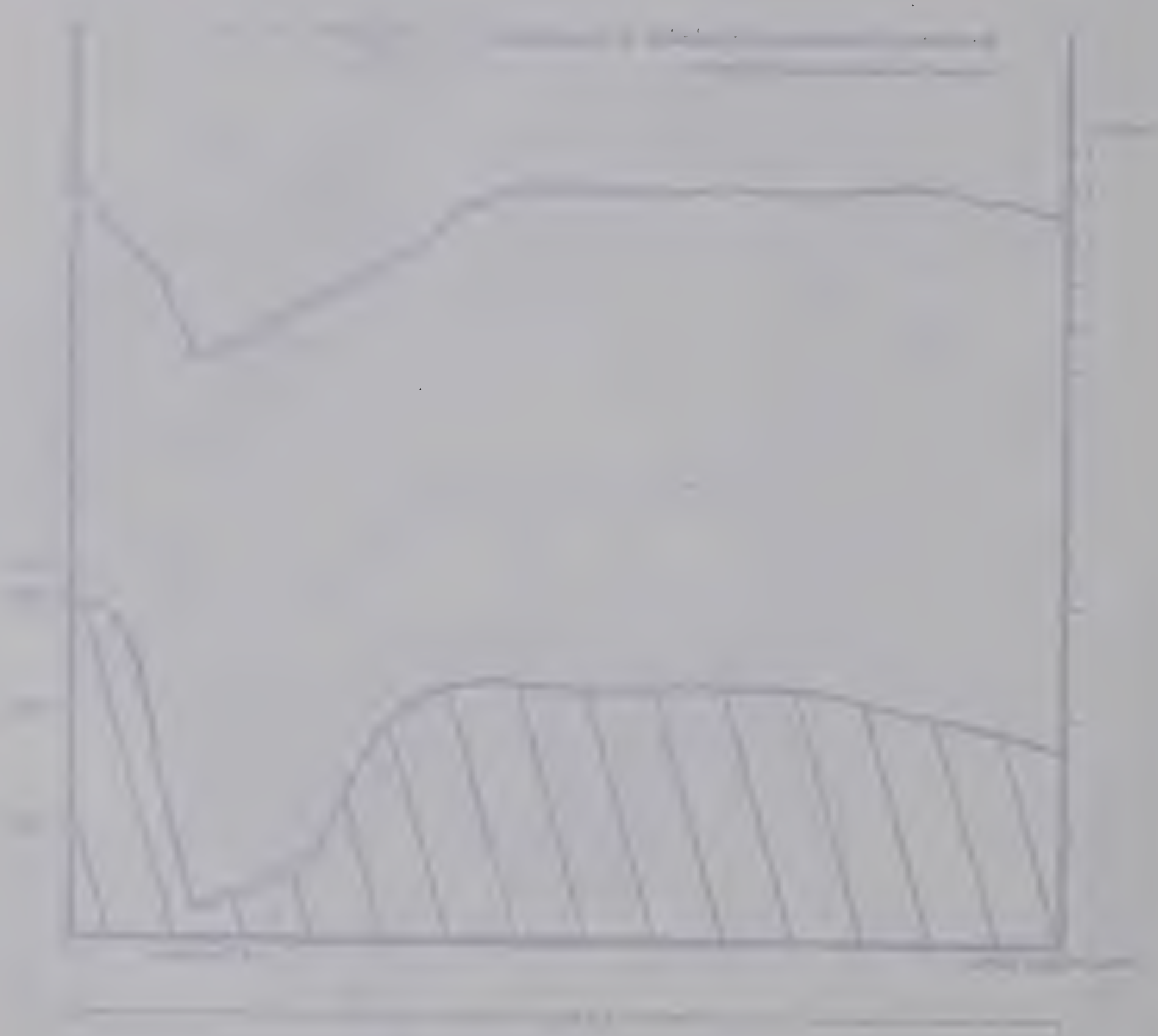

Rochester; Temperature in Relation to Topography
Segment from Meteorological Station to B
Temp (°C)
4
3
2
1
0
-1
Elev (ft)
2250
2150
2050
Meteorological Station
R. Tawatinaw
B
4.2 miles

Figure B.32



a temperature inversion of 3.7°C (6.7°F) occurred in the valley of the Tawatinaw. Cold air drainage is obviously facilitated by the steep sides of the valley which provide 'shelter' to high winds. The temperature profile also indicates, despite the wind strength, the slightly lower temperature recorded at the station site compared with those of the surrounding higher land. It is surmised that if the wind speed had been slight both the inversion and the temperature differential between the top of the plateau and the station site would have been much greater. This certainly was the case with regards to the Meanook sample area which has already been discussed. The Meanook station is situated within the same topographic features as the Rochester station, 19 miles to the northeast. The analysis of the Rochester temperature traverse in association with the Meanook temperature traverses, suggests that the Rochester records are a fair representation of the western third of the sample area, that is, the area enclosed by the 2125' contour, and the valley of the Tawatinaw River. The higher levels of the plateau, especially those over 2175' most probably benefit from longer frost-free periods than suggested by the Rochester records. For those very limited areas over 2225' the Meanook records would be more appropriate.

Vilna Sample Area

The Vilna sample area is situated in Smoky Lake County, its coordinates being NW 1/4 5/59/15; SW 1/4 6/58/15; NE 1/4 5/59/13 and SE 1/4 6/58/13 west of the 4th meridian. The site of the meteorological station and the location of the sampled farmsteads and farm holdings in relation to topography are illustrated by Figure B.33. The contours were drawn from the 1:250,000 sheet. Although altimeter

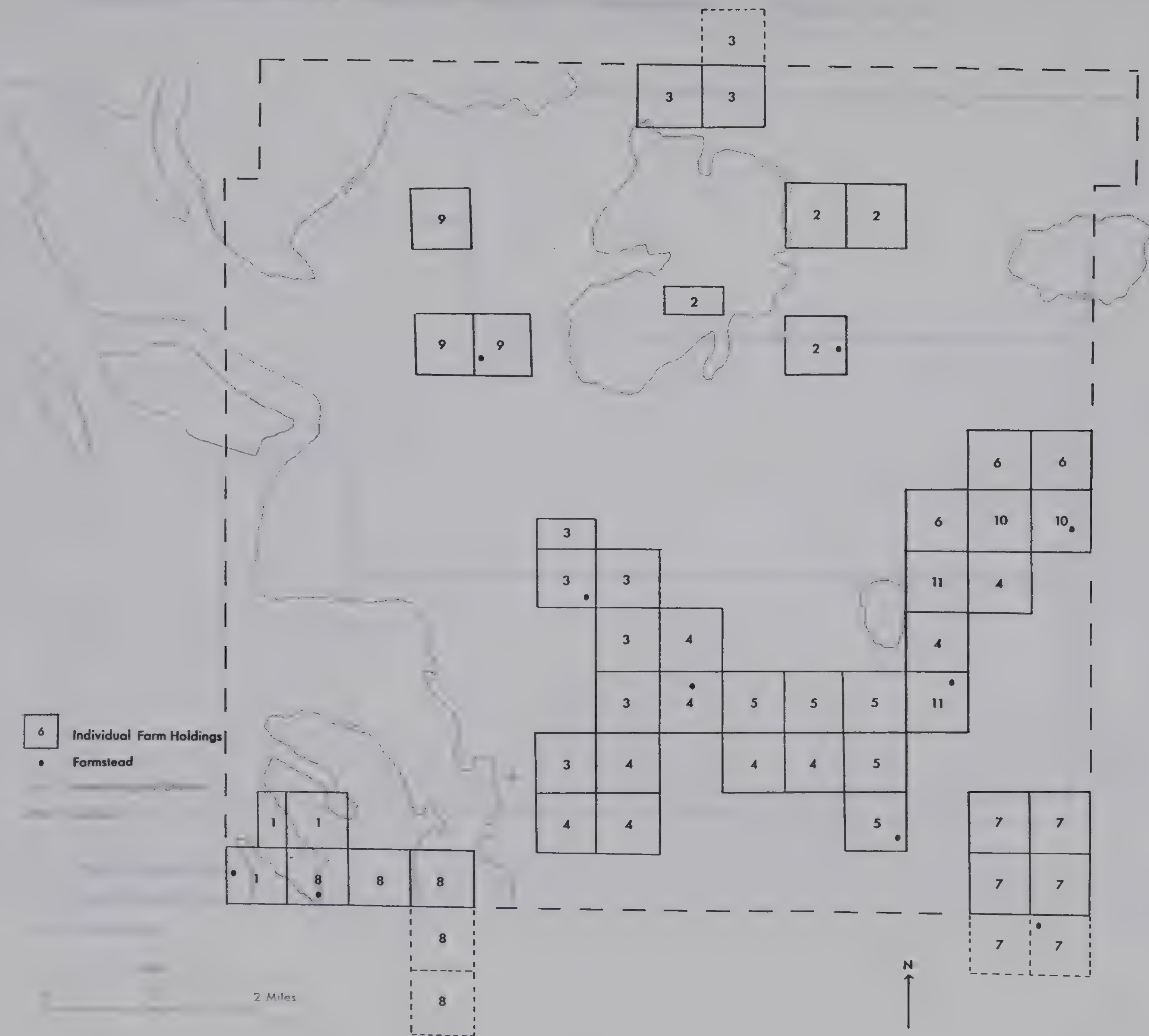
measurements were taken, no further contours were interpolated beyond those of the base sheet partly because of the questionable nature of the contours on the base map, but more importantly because of the nature of the relief itself. The altimeter readings were used, however, in determining direction of slope in the temperature traverse cross-profiles. The relief of the area ranges between 1950' and 2200' with the North Saskatchewan River, at its nearest point, one mile beyond the southern boundary. There is a predominance of gentle slopes and undulating land, intersected by occasional steep-sided, but usually small scale, ridge and creek features. It is this combination of gentle slopes and infrequent sharp breaks that cause such difficulties in mapping relief features. Most of the area is open farmland although there are outcrops of tree-covered sterile sandy soils. A few small water bodies occur on the eastern margin but these were not drawn on the base map.

The meteorological station is located in the southwest quadrant of the area at a height of approximately 2100 ft. The station site is well exposed in an open area 75 ft. north-northeast from the nearest building. The surrounding area is gently rolling rough pasture containing several groves of trees and with a slight rise to the north. In 1963 the Stephenson Screen was relocated to its present site, from a slightly higher elevation to the north. However the change in height was only a matter of a few feet and the distance involved in the relocation only about 100 yards. Table B.10 indicates an extremely short frost-free season which in many respects is similar to Newbrook. The longest frost-free season was only 109 days (1961), with 1963 the only other year enjoying more than 100 frost-free days. Like Newbrook the

shortest frost-free seasons were in 1966 (28 days), 1968 (39 days) and 1959 (61 days), whilst the killing frost-season in 1968 was only 59 days. The first fall frost in 1968 occurred on August 9 and the first killing frost on August 13. Frosts occurred in July and August in five of the ten years under study. The probability of spring frosts after May 15 is 100% and after June 1 is 70%, whilst the probability of a fall frost before August 31 is 50% and by September 10 there is a 100% chance of a fall frost. Killing frost probabilities for the same dates are 90% and 40% in the spring, and 10% and 60% in the fall.

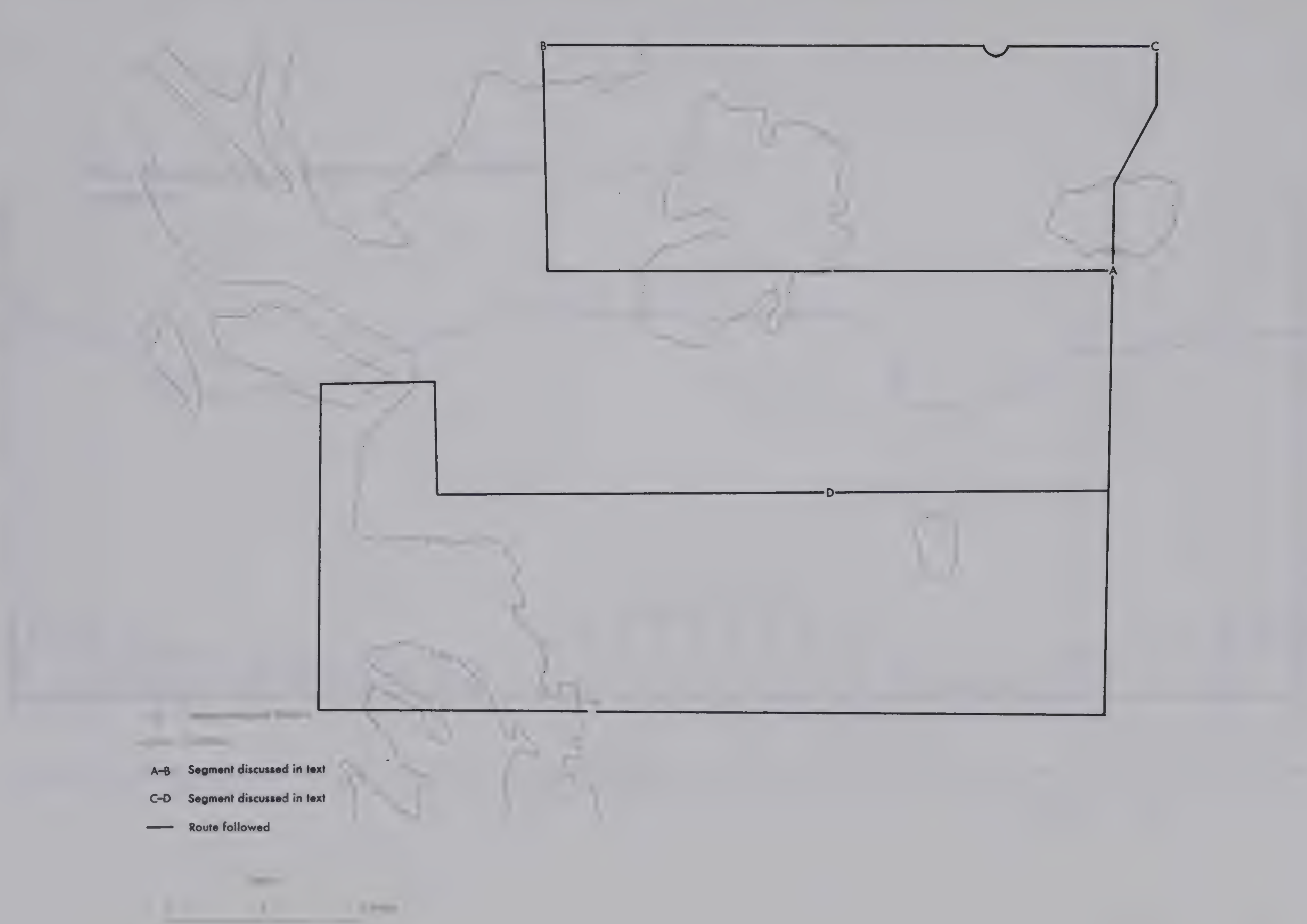
In order to assess the representativeness of the records outlined above, a temperature traverse was conducted in the early hours of October 13, 1969. Unlike most of the other traverses this one was not conducted around sunrise but between 2 a.m. and 3:30 a.m. when weather conditions were appropriate, completely clear skies and no wind. The temperature dropped only 2.3°F (1.3°C) during the course of the traverse, from 27.1°F (-2.7°C) to 24.8°F (-4.0°C) so that very little adjustment was necessary. Assuming a constant drop in temperature this is only a little over 1°F temperature change in 45 minutes. The highest temperature recorded on the traverse was -2.7°C (27.1°F), recorded at the station, and the minimum was -7.5°C (18.5°F), so that without adjustment, the maximum variation was 4.8°C (8.6°F). Figure B.34 shows the route of the traverse and Figure B.37 the distribution of adjusted minimum temperatures in relation to that recorded by the station. This shows clearly that for most of the route followed, the temperature change was small. This is substantiated, in part, by an earlier traverse conducted around sunrise on September 27. The results of this traverse are not shown here because for approximately half the traverse, the pens

Vilna Sample Area Figure B.33

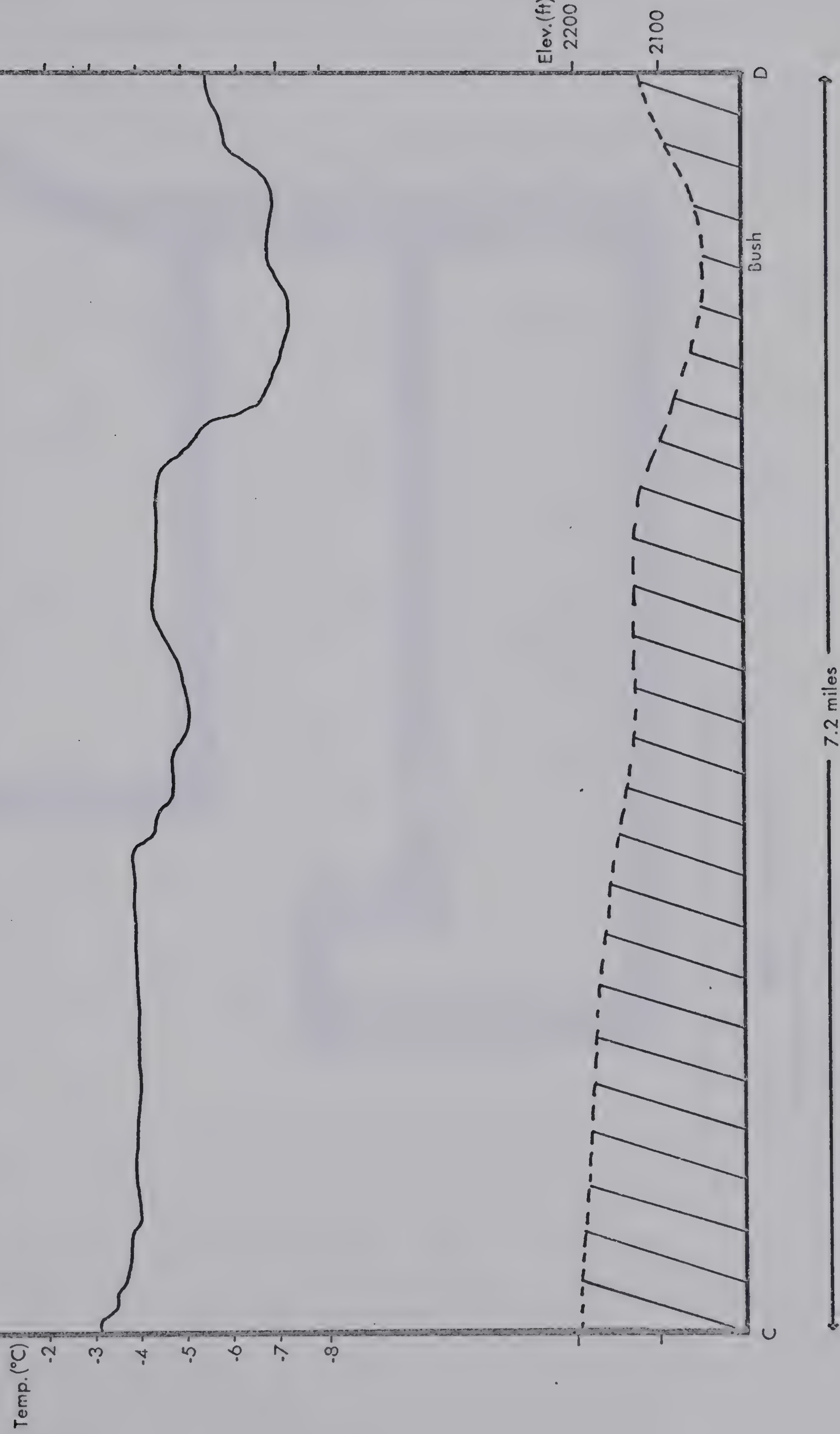


Vilna Route of Temperature Traverse in Relation to Topography

Figure B.34



Vilna; Temperature in Relation to Topography   Figure B.35



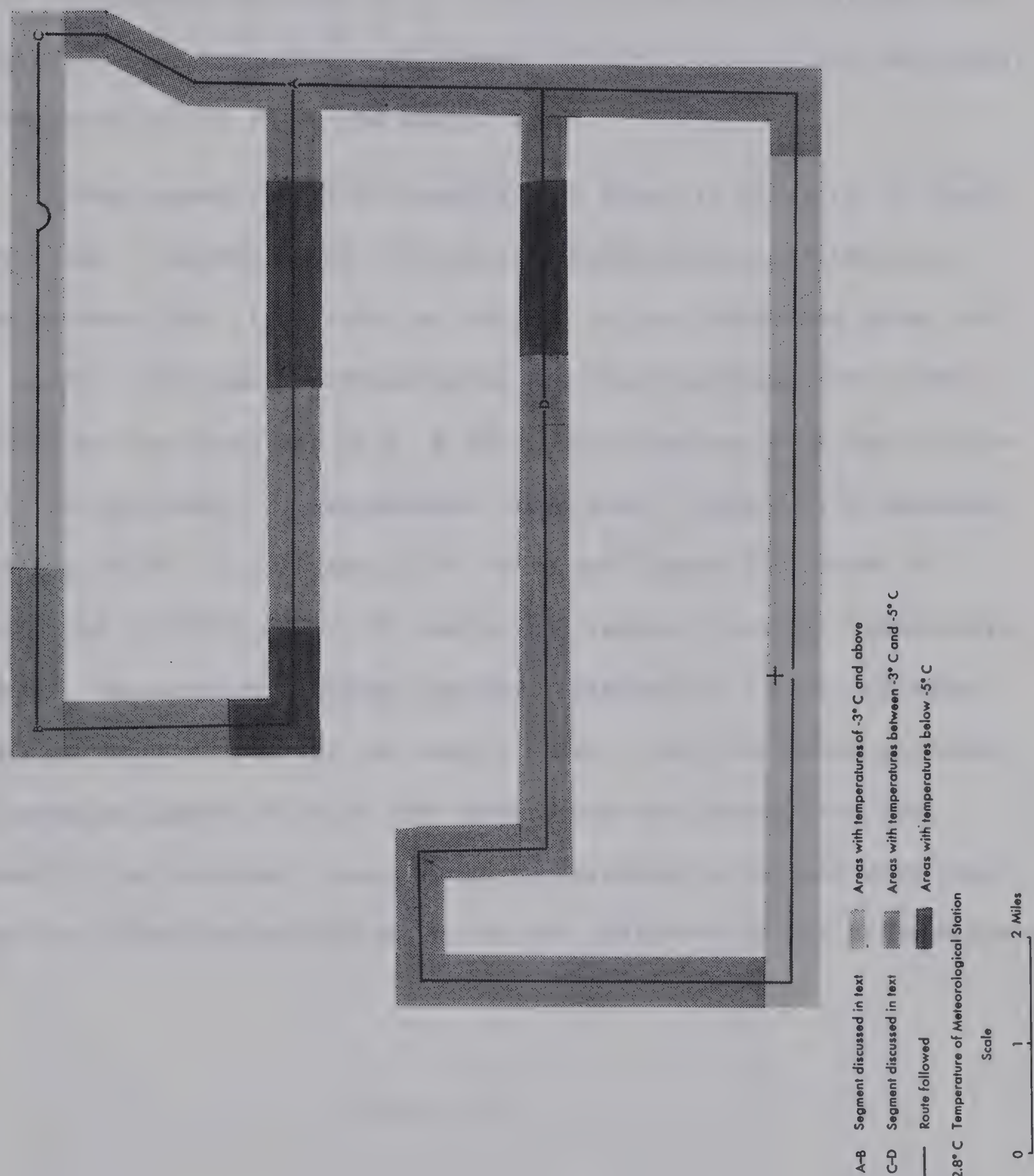
Vilna; Temperature in Relation to Topography

Segment C-D

Figure B.36

Figure B.37

Vilna Distribution of Minimum Temperatures Oct 13th 1969



recording the temperature on the thermograph failed to connect with the paper. However when the thermograph did record properly a maximum temperature variation of only 2.0°C (3.6°F) was recorded and again the highest temperature was that of the station. This would indicate very strongly that the meteorological records of the Vilna station are fairly representative of at least the sample area.

Two segments of the traverse were drawn in relation to topography (Figs. B.35 and B.36). These particular corss-profiles were chosen because they illustrate the largest of the inversions along the whole route. The points between which the cross-sections were drawn are shown on the route map (Fig. B.34). Both diagrams show how shallow dips in relief result in temperature inversions. Figure B.35 contains inversions of 2°C (3.6°F) and 2.2°C (4°F) and Figure B.36 shows an inversion of 3.0°C (5.4°F). To sum up the results from the temperature traverses, the station at Vilna has been assessed as a true indicator of minimum temperatures for the sample area. Along the route selected there were no points at which the temperature was higher than that recorded by the station. Overall the temperature variations were small except for a few shallow hollows which are indicated by the cross-sections.

* * * * * *

On the basis of the 1959-68 period, a summary of the probabilities of frost at 32°F and 28°F for dates in the spring and fall are given in Table B.11.

Table B.1 Meanook Frost-Free and Killing Frost-Free Season 1959-68

	Frost-Free Period (Days)		Date of Last Spring and First Fall Frost			
	32°F	28°F	32°F		28°F	
1959	107	139	May 25	September 9	May 13	September 29
1960	143	157	May 19	October 9	May 5	October 9
1961	120	124	May 13	September 10	May 12	September 10
1962	113	123	May 13	September 3	May 8	September 8
1963	120	163	May 20	September 17	May 20	October 30
1964	119	181	May 14	September 10	April 28	October 26
1965	109	155	May 20	September 6	April 21	September 23
1966	143	165	May 13	October 3	April 30	October 12
1967	145	163	May 11	October 3	May 11	October 21
1968	125	133	May 18	September 20	May 10	September 20
Averages	124	150	May 17	September 18	May 7	October 4

Source: Department of Transport, Meteorological Branch, Monthly Records 1959-68.

Table B.2 Cold Lake Frost-Free and Killing Frost-Free Season 1959-68

	Frost-Free Period (Days)		Dates of Last Spring and First Fall Frost			
	32°F	28°F	32°F		28°F	
1959	108	125	May 26	September 9	May 26	September 29
1960	156	162	May 6	October 9	May 5	October 14
1961	109	113	May 17	September 3	May 13	September 3
1962	113	153	May 13	September 3	May 8	October 9
1963	122	155	May 21	September 20	May 5	October 7
1964	122	138	May 11	September 10	May 11	September 26
1965	105	115	May 21	September 3	May 21	September 13
1966	151	153	May 2	September 30	April 30	September 30
1967	93	135	June 22	September 23	May 11	September 23
1968	94	140	July 1	October 3	May 16	October 3
Averages	117	139	May 23	September 17	May 12	September 28

Source: Department of Transport, Meteorological Branch, Monthly Records 1959-68.

Table B.3 Lac La Biche Frost-Free and Killing Frost-Free Season 1959-68

	Frost-Free Period (Days)		Dates of Last Spring and First Fall Frost			
	32°F	28°F	32°F		28°F	
1959	107	139	May 25	September 9	May 13	September 29
1960	124	157	May 25	September 26	May 5	October 9
1961	108	123	May 17	September 2	May 13	September 13
1962	101	123	May 24	September 2	May 8	September 8
1963	116	156	May 27	September 10	May 20	October 23
1964	122	151	May 11	September 10	April 28	September 26
1965	72	108	June 23	September 3	May 21	September 6
1966	109	156	June 7	September 24	April 30	October 3
1967	90	111	June 23	September 21	June 4	September 23
1968	60	90	June 14	August 13	May 15	August 13
Averages	101	131	June 1	September 10	May 13	September 21

Source: Department of Transport, Meteorological Branch, Monthly Records 1959-68.

Table B.5 Athabasca II Frost-Free and Killing Frost-Free Season 1959-68

	Frost-Free Period (Days)		Date of Last Spring and First Fall Frost			
	32°F	28°F	32°F		28°F	
1959	104	119	May 28	September 9	May 13	September 9
1960	123	149	May 16	September 16	May 6	October 2
1961	117	121	May 16	September 10	May 12	September 10
1962	115	124	May 10	September 2	May 7	September 8
1963	113	154	May 27	September 17	May 9	October 10
1964	123	135	May 10	September 10	April 28	September 10
1965	73	117	June 23	September 4	May 21	September 15
1966	141	155	May 15	October 3	May 1	October 3
1967	110	138	June 14	September 23	May 11	September 26
1968	56	129	June 14	August 9	May 14	September 20
Averages	106	134	May 27	September 10	May 9	September 20

Source: Department of Transport, Meteorological Branch, Monthly Records 1959-68.

Table B.6 Iron River Frost-Free and Killing Frost-Free Season 1959-68

	Frost-Free Period (Days)		Dates of Last Spring and First Fall Frost			
	$32^{o}F$	$28^{o}F$	$32^{o}F$		$28^{o}F$	
1959	103	106	May 29	September 9	May 26	September 9
1960	85	151	June 8	September 1	May 11	October 9
1961	109	113	May 17	September 3	May 13	September 3
1962	113	123	May 23	September 3	May 8	September 8
1963	121	139	May 22	September 21	May 21	October 7
1964	97	150	June 1	September 6	April 29	September 26
1965	105	109	May 21	September 3	May 21	September 6
1966	121	156	May 15	September 13	April 30	October 3
1967	109	135	June 6	September 23	May 11	September 23
1968	87	140	May 19	August 13	May 16	October 3
Averages	105	132	May 25	September 7	May 13	September 21

Source: Department of Transport, Meteorological Branch, Monthly Records 1959-68.

Table B.7 Elk Point Frost-Free and Killing Frost-Free Season 1959-68

	Frost-Free Period (Days)		Dates of Last Spring and First Fall Frost			
	32°F	28°F	32°F		28°F	
1959	101	106	May 31	September 9	May 26	September 9
1960	100	138	May 23	August 31	May 6	September 21
1961	108	108	May 17	September 2	May 17	September 2
1962	102	118	May 24	September 3	May 8	September 3
1963	119	122	May 22	September 18	May 21	September 20
1964	101	152	June 1	September 10	April 28	September 27
1965	108	108	May 21	September 6	May 21	September 6
1966	115	144	June 7	September 30	May 12	October 3
1967	111	111	June 4	September 23	June 4	September 23
1968	84	133	May 18	August 10	May 16	September 26
Averages	105	124	May 26	September 8	May 16	September 17

Source: Department of Transport, Meteorological Branch, Monthly Records 1959-68.

Table B.8 Newbrook Frost-Free and Killing Frost-Free Season 1959-68

	Frost-Free Period (Days)		Dates of Last Spring and First Fall Frost			
	32°F	28°F	32°F		28°F	
1959	45	102	June 28	August 12	May 30	September 9
1960	84	132	June 4	August 27	May 15	September 24
1961	108	109	May 17	September 2	May 17	September 3
1962	94	123	May 31	September 2	May 8	September 8
1963	63	123	June 23	August 25	May 20	September 20
1964	58	102	May 31	July 28	May 31	September 10
1965	72	108	June 23	September 3	May 21	September 6
1966	23	125	June 29	July 22	May 14	September 16
1967	77	111	June 23	September 8	June 4	September 23
1968	48	60	June 22	August 9	June 14	August 13
Averages	67	109	June 14	August 20	May 24	September 10

Source: Department of Transport, Meteorological Branch, Monthly Records 1959-68.

Table B.9 Rochester Frost-Free and Killing Frost-Free Season 1959-68

	Frost-Free Period (Days)		Dates of Last Spring and First Fall Frost			
	32^oF	28^oF	32^oF		28^oF	
1959	62	107	June 28	August 29	May 25	September 9
1960	93	121	June 2	September 3	May 18	September 16
1961	116	117	May 17	September 10	May 16	September 10
1962	101	123	May 24	September 2	May 8	September 8
1963	89	134	June 23	September 20	May 9	September 20
1964	31	122	June 27	July 28	May 16	September 15
1965	72	116	June 23	September 3	May 20	September 13
1966	64	111	June 9	August 12	June 7	September 26
1967	34	130	June 22	July 26	May 18	September 23
1968	-	-	-	-	-	-
Averages	73	120	June 13	August 25	May 19	September 16

Source: Department of Transport, Meteorological Branch, Monthly Records 1959-68.

Table B.10 Vilna Frost-Free and Killing Frost-Free Season 1959-68

	Frost-Free Period (Days)		Dates of Last Spring and First Fall Frost			
	32°F	28°F	32°F		28°F	
1959	61	102	June 28	August 28	May 30	September 9
1960	87	115	June 1	August 27	June 1	September 24
1961	109	109	May 17	September 3	May 17	September 3
1962	94	123	May 31	September 2	May 8	September 8
1963	104	122	May 27	September 8	May 21	September 20
1964	70	101	June 26	September 4	June 1	September 10
1965	69	108	June 23	August 31	May 21	September 6
1966	28	135	June 24	July 22	May 16	September 30
1967	77	109	June 23	September 8	June 6	September 23
1968	39	59	July 1	August 9	June 15	August 13
Averages	75	109	June 14	August 28	May 26	September 12

Source: Department of Transport, Meteorological Branch, Monthly Records 1959-68.

Table B.11 Probabilities (%) of Frost and Killing Frost 1959-68

	Spring		32°F	Fall	
	May 15	June 1		August 31	September 10
Athabasca	70	30		10	60
Meanook	50	0		0	50
Rochester	100	80		50	100
Newbrook	100	60		60	100
Lac La Biche	90	40		10	60
Vilna	100	70		50	100
Iron River	80	30		10	60
Cold Lake	60	20		0	80
Elk Point	100	30		20	60
			28°F		
	Spring			Fall	
Athabasca	10	0		0	40
Meanook	10	0		0	20
Rochester	80	10		10	40
Newbrook	80	20		10	60
Lac La Biche	30	10		0	30
Vilna	90	40		10	60
Iron River	30	0		0	40
Cold Lake	30	0		0	40
Elk Point	40	10		0	30

APPENDIX C

FROST - JUNE 10, 11 & 12, 1969 & EFFECTS

Location (P.O.)	of Frost	Duration (Hours)	Crop	Stage	Seed Bed Moisture	Initial Observations (1st day or 2nd)	Later Observations (2 weeks ±)	Action Taken	Other Comments

Source: Questionnaire Issued by Provincial Government to all District Agriculturalists, June 1969.